CYCLOPÆDIA
OF
USEFUL ARTS & MANUFACTURES,
Edited by
CHARLES TOMLINSON.

The Great Britain leaving Liverpool, 1853.

GEORGE VIRTUE, LONDON & NEW YORK.

CYCLOPÆDIA OF USEFUL ARTS,

Mechanical and Chemical,

MANUFACTURES, MINING, AND ENGINEERING.

EDITED BY CHARLES TOMLINSON.

VOL. II.

HAMMER TO ZIRCONIUM.

THE WHOLE ILLUSTRATED BY FORTY STEEL ENGRAVINGS,
AND TWO THOUSAND FOUR HUNDRED AND SEVENTY-SEVEN WOOD ENGRAVINGS.

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TO

WILLIAM ALLEN MILLER, ESQ., M.D., F.R.S.,

PROFESSOR OF CHEMISTRY IN KING'S COLLEGE, LONDON.

MY DEAR SIR,

On the completion of this Cyclopædia of Useful Arts, &c., it is with peculiar satisfaction that I dedicate to you the Second Volume of a work, throughout the whole of which I have had the advantage of being able to consult you on points connected with Chemical Art. A similar privilege, with respect to Mechanical and Engineering subjects, was granted me by our regretted friend, the late Professor Cowper, to whom the first volume of this Cyclopædia was dedicated.

Such assistance as this may be some excuse for my temerity in undertaking, four years ago, to prepare so comprehensive a work as the present. I have been also indebted to some other valued friends for advice and assistance: namely, W. H. HATCHER, Esq.; Dr. GEORGE WILSON, of Edinburgh; E. L. GARBETT, Esq; GEORGE DODD, Esq.; and CHARLES COWPER, Esq. The liberality and kindness of various manufacturing firms are acknowledged in the body of the work; and I have also been careful to give the titles, &c., of such books, and the names of such persons, as have afforded me information.

Still the task of planning and executing the great bulk of the work has necessarily fallen upon me. I am aware of many imperfections in it (some of which are due to the pressure arising from the plan of publication in monthly numbers); but it has been my endeavour not to aim above the powers of my own mind, or the capacities of my readers, but simply to present a popular exposition ot the Useful Arts and Manufactures. But as I form a somewhat high estimate of the standard which should be maintained in popular instruction, it may be said that in some cases, I have entered too minutely into the science of technical

subjects to adapt them for popular teaching. Such, however, is not my experience. If a work so purely scientific as my "Introduction to the Study of Natural Philosophy" could find, within a very few years, as many as 47,000 readers, I think I am justified in supposing that there is a very large class of persons to whom intellectual food is as necessary as food for the body, and who require fresh supplies of the one as much as of the other. If so, it is evidently the duty of writers and publishers to see that this intellectual food be wholesome, nutritive, and well adapted to the wants of persons whose limited means forbid a large supply. Readers of this class have not, like your pupils, the opportunity of following out, in a methodical manner, the principles of science which form the true and only basis of technical knowledge. Such invaluable instruction is seldom within their power, and they should therefore find in the books which enterprising publishers place within their reach, so full and complete an enunciation of principles as to render details easy and processes intelligible.

If you will accept a work which has such modest claims to the attention of men like yourself, you will strengthen the motives which, during many years, have increased my respect for you as a Christian philosopher, and my affection for you as a friend.

I remain,

My dear Sir,

Your attached Friend,

CHARLES TOMLINSON.

Bedford Place, Ampthill Square.

CYCLOPÆDIA OF USEFUL ARTS,

Mechanical and Chemical,

MANUFACTURES, MINING AND ENGINEERING,

HAMMER. The hammer is perhaps the most remarkable and valuable of all the implements which man employs in moulding and submitting to his use the various objects around him. It illustrates the principle of the *permanence* of the force of communicated motion; it constitutes the force of impact, and is the most powerful of weapons. "Were there no tendency to *permanence* in the force of motion which his hammer acquires in its descent, its power on the substance which the artificer seeks to shape out would only be the same as though he were to lay it gently down upon it: its impact would be no greater force than the *pressure* of its weight. So far is this, however, from being the case, that, as it is well known to the workman, a slight blow from the lightest hammer is sufficient to abrade a surface which the direct pressure of a ton weight would not make to yield. There is no force in nature comparable to that of impact."[1]

The term hammer is usually applied to the well-known tool consisting of an iron head fixed crosswise upon a handle of wood; but the hammers employed in the useful arts are very varied in form, and the weights of individual examples may be estimated from that of several tons to a fraction of an ounce. The largest hammer is the *helve*, or *forge-hammer*, used in the operation of shingling in the manufacture of *iron:* this weighs from 4 to 8 tons. The helve is also used in forging *steel* ingots; but when they are sufficiently reduced by this means, the *tilt-hammer* comes into operation, and is made to move with great rapidity under the action of springs instead of by gravity alone.

In the ordinary practice of FORGING, the smith employs a variety of hammers with the *panes* or narrow edges made in different ways, either at right angles to the handle, parallel with the same, or oblique: but the work done by these hammers is often accomplished with more precision by what are called *set-hammers;* those with flat faces are made like hammers, and usually with similar handles, and for the convenience of reversing are not wedged in: these tools, instead of striking, are struck upon the work with the sledge-hammer. Other similar tools, with broad faces, are called *flatters:* top-tools, with narrow round edges like the pane of the hammer, are called *top-fullers:* they are held to the work with hazel-rods, as noticed in the article CUTLERY, where the hammers used by the Sheffield cutlers are described. The hammers used in forging blanks for files, and for cutting the teeth, are described under FILE. The *hand-hammer* used by the smith is of such weight that it may be governed with one hand at the anvil. The *sledge-hammer* and the *monkey*, or *vertical hammer*, are noticed in FORGING. The sledge-hammer has its varieties, which usually consist of the *up-hand sledge*, which is used with both hands, and seldom lifted above the head, and the *about-sledge*, which is held by both hands at the furthest end of the handle, and being swung at arm's length over the head, is made to fall upon the work with as heavy a blow as possible. Referring to the sledge, Mr. Holtzapffel remarks:—"It is used *up-hand* for light work; the right hand being slid towards the head in the act of lifting the hammer from off the work, and slipped down again as the tool descends: and the conditions are scarcely altered when the smith swings the hammer about in a circle, the signal for which is 'About sledge;' whereas when, in either case, the blows of the sledge-hammer are to be discontinued, the fireman taps the anvil with his hand-hammer, which is, I believe, an universal language." The *riveting-hammer* is the smallest used by smiths.

In the practice of forging, small tilt-hammers to be worked by the foot have often been introduced; but they are not successful, because, when one man has to manage the whole, his attention is too much divided, nor is his strength equal to the work. The best form of these *lift-hammers* is that called *the Oliver*, Fig. 1118. "The hammer head is about $2\frac{1}{2}$ inches square, and 10 inches long, with a swage tool, having a conical crease attached to it, and a corresponding swage is fixed in a square cast-iron anvil block, about 12 inches square, and 6 deep, with 1 or 2 round holes for punching, &c. The hammer-handle is from 2 to $2\frac{1}{2}$ feet long, and mounted in a cross spindle nearly as long, supported in a wooden frame, between end screws, to adjust the groove in the hammer-face to that in the anvil-block. A short arm, 5 or 6 inches long, is attached to the right end of the hammer axis, and from this arm proceeds a cord to a

(1) Moseley: "Illustrations of Mechanics." Third Edit. 1846.

spring-pole overhead, and also a chain to a treadle a little above the floor of the smithy. When left to itself, the hammer-handle is raised to nearly a vertical position by the spring, and it is brought down very readily with the foot, so as to give good hard blows

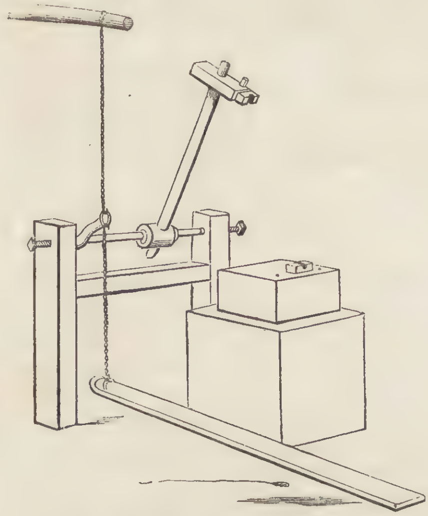


Fig. 1118. THE OLIVER.

at the commencement of moulding the objects, and then light blows for finishing them." Mr. Holtzapffel saw this machine at work making long stout nails, intended for fixing the tires of wheels, secured within the felloes by washers and riveting: the nails were made very nicely round and taper, and were forged expeditiously.

The *raising-hammer*, for raised works in metal, is rounded at the edge, and of various forms. The *planishing-hammer* has a flat smooth face; the *gold-beater's hammer*, a somewhat rounded one; the *hack-hammer*, for correcting distortions which so commonly occur in hardening steel goods, terminates at each end in an obtuse chisel edge. The hack-hammer used for hacking grindstones is a small adze of 2 or 3 lbs. weight, but longer and more curved in the blade, and with a very short handle. Its use is to hack or notch the high places which occur in large grindstones, in regular work, and arise from unequal wear. For this purpose the high places are marked by holding a piece of chalk or charcoal steadily upon the horse, and bringing it gradually near the stone before it comes to rest, the strap having been thrown off. The grinder then cuts shallow oblique furrows, about an inch apart, in the high places denoted by the marks, and crosses them with others so as to produce a chequered surface. On again using the stone the greatest wear occurs at these roughened places, and thus the stone is restored to its true form.

The *veneering-hammer* is of iron, with a very wide thin pane; but it is often formed of wood.

The STEAM-HAMMER will be described under that head.

HARBOUR is the general name given to any haven or port communicating with the sea, or with a navigable river or lake of sufficient depth to float ships of considerable size. A good harbour should be free from rocks or shallows: the opening should be of sufficient extent to admit large ships at all times of the tide: it should have good anchorage ground, and be easy of access, and well defended from the violence of the wind and of the sea: it should be sufficiently capacious for the reception of the shipping of different nations, and deep enough to allow ships to lie close alongside quays or piers, that the expense and inconvenience of loading and unloading by means of lighters may be avoided: it should be furnished with a good lighthouse, and have proper rings, posts, moorings, &c., to remove or secure vessels. Portsmouth, Milford Haven, and the Cove of Cork, are the finest harbours in the British Islands, and are surpassed by few, if any, in the world. The accompanying steel engraving represents the harbour of Whitehaven in Cumberland, situate at the upper end of a small creek of the Irish Sea. This harbour is spacious and commodious, having seven piers extending into the sea in different directions, and affording ample security to shipping. Attached to the harbour is a patent slip; there are two lighthouses at the entrance, and a third situate on the promontory of the Bee's Head, 3 miles to the south-west. The commerce of this harbour is very extensive.

HARDWARE, a term applied to goods manufactured from metals, such as iron, steel, copper, brass, &c. Birmingham and Sheffield are the chief seats of the manufacture in this country.

HARPOON, or HARPING-IRON, a javelin used for piercing whales in the whale-fishery: it has a broad, flat, triangular, barbed head, sharpened so as to penetrate easily, and a shank about 2 feet long, to the extremity of which is fastened a long line coiled up in the boat, so that it may run out easily without entangling. See OIL.

HARTSHORN. See AMMONIA.

HAT. The manufacture of hats brings into operation the curious and interesting process of *felting*, which is the interlacing of animal fibres so as to produce, without weaving, a dense and compact cloth. This is caused by the peculiar structure of the hair and wool of animals, which though apparently smooth and regular, may be detected under the microscope as notched or jagged at the edges, the teeth invariably pointing upwards, that is, from the root towards the point. From a similar example in the vegetable world, namely, an awn of barley, we find that where this notched structure exists, the fibre when rubbed will move in one direction only. An awn of barley root upwards will travel up the coat sleeve, by the slight friction between it and the arm. The same kind of motion, though inferior in degree, is possessed by fibres of clean wool and hair, so that when subjected to gentle friction, assisted by moisture, the fibres mat together and form the kind of cloth called *felt*. The felting property of wool is greatly assisted by the crinkled or zig-zag figure of the fibre, which is retained with great pertinacity, so that if drawn out straight, it immediately contracts again on being let go; thus the forward motion of

the fibre, under friction, is partly counteracted, or converted into a circular or zig-zag motion, which is just that which most completely effects the matting together of the various fibres. So great is this tendency, that in a flock bed or mattress the carded

Fig. 1119. A FIBRE OF SAXONY LAMBS'-WOOL, HIGHLY MAGNIFIED.

wool of which it is made is constantly felting itself into knots, and requires to be pulled apart or to be carded afresh at intervals. Wool in the yolk, or with the natural grease adhering to it, cannot be felted, the roughness of the fibre being in that case filled or smoothed over by the oil.

A remote origin is ascribed to felt, which is said to have been the *lana coacta* of the ancients, worn as cloaks by soldiers, and to have been the material of the Lacedemonian hats. But the word rendered *felt* by some writers, is by others translated *knitted wool*, therefore, without occupying ourselves with the early portion of its history, it may be sufficient to state, that towards the close of the sixteenth century there is no doubt of its employment, for beaver hats were then in use in England, and became so popular, that in the next century Heywood, writing of varieties of head gear, concluded with, " But of all *felts* that may be felt, give me your English beaver."

An old hatter informed the writer, that in his youth an annual festival was held on St. Clement's Day, (23d November,) this saint being the reputed inventor of felt, and that in Ireland and other Roman Catholic countries, the hatters still hold their festival on this day. St. Clement, perhaps, was the saint who is said to have put carded wool in his sandals to protect his feet on a pilgrimage, and who found at its close, that the wool had felted itself into cloth.

Beaver hats were at first regarded as a great curiosity, and fetched a high price, considering the value of money in those days. In 1585, Stubbs wrote, " And as the fashions be rare and strange, so is the stuffe whereof these hattes be made divers also; for some are of silke, some of velvet, some of taffatie, some of sarcenet, some of wooll, and, which is more curious, some of a certain kind of fine haire. These they call beaver hattes, of xx, xxx, or xl shillings price, fetched from beyonde the seas, from whence a greate sorte of other vanities doe come besides."

The supply of beaver for this manufacture is received through the Hudson's Bay Company, but owing to the gradual extermination of the beaver in many countries where it was once common, and the consequent failure in the imports of beaver, the fur of several other animals is come into use as a substitute. Thus the hair of the Coypou, whose skin is sold as *nutria skin*, that of the musquash or musk-rat, the fine down from the back of the common hare, and the fur of the rabbit, are all used in the hat manufacture. The furs in question form the nap of the hat; the body of the hat is made of lamb's wool, carefully washed, scoured, dried, and carded. The woolly hair of the Llama, or Vicuna, a species of camel, native of the Andes, is also used for the purpose. The structure of some of these hairs is shown in the following figures.

Fig. 1120. STRUCTURE OF BEAVER-DOWN.

Fig. 1121. MUSQUASH.

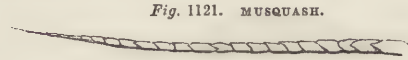


Fig. 1122. NUTRIA.

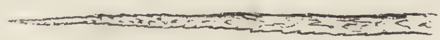


Fig. 1123. HARES'-DOWN.

Fig. 1124. RABBITS' FUR.

The manufacture of hats from beaver, or from the furs used as substitutes, is conducted in the following manner; but it must be premised, that the demand for such hats is now comparatively small, on account of the perfection to which silk hats have been brought. The first operations belong to the furrier, and consist, first, of the cleansing of the skins by thorough washing in soap and water, after which the long coarse hairs are pulled out by a woman seated on a low stool, with the skin fastened to her knee by a strap passing over the skin and under the foot. She pulls out the long hairs by the roots with a jerking motion, seizing them between the thumb and the edge of a blunt knife. After all the long hairs are removed by this process, which is called *pulling* or *forcing*, the fine down or fur is next shorn from the skin by a sharp blade, applied either by hand or by machinery. By a simple but effective contrivance, the fur is then sorted into different degrees of fineness. A current of air conveys it along a horizontal trunk, and as it floats along, the filaments are separated, and are carried to a greater or less distance according to their weight, the coarse and heavier filaments falling down first, and the finer and lighter continuing longer afloat, and being deposited considerably in advance. Thus, when the blast of air ceases, it is only necessary to open the trunk and select the various qualities as they lie ready sorted to the hand.

The succeeding operations are carried on in the beaver-hat factory. According to the kind of hat required, the beaver, some inferior fur, or lamb's wool, are selected for operating on. The beaver hat, properly so called, consists of a body or foundation of rabbit's fur and a beaver nap, but the latter is frequently mixed with some other fur. Another kind

of hat is made with the body of lamb's wool, and the nap of musquash, nutria, or some cheaper fur than beaver. This is called a *plate* hat, to signify, probably, that the outer layer only is of fur, the inner of felted wool, just as in plated articles the outside only is of the genuine material. A third kind of hat is the *felt* hat, in which the body is of wool and no nap is added. Supposing the hat to be one in which the body is of wool, and the plate or nap is of a superior kind, the processes are as follows. In the factory visited by the Editor, the fur is weighed out, mixed, and formed into a nap, in a low unventilated apartment, where every precaution is adopted to keep the air stagnant, that none of the precious material be wafted away and lost. One side of this apartment is occupied by a broad bench or

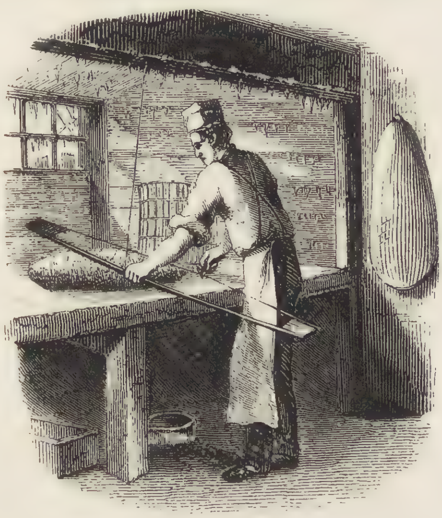


Fig. 1125. BOWING.

counter, partitioned off into spaces of about five feet every way, each space being lighted by a window, constructed so as not to open. See Fig. 1125. Before each window stands a workman, performing the delicate and ingenious operation of *bowing* the fur, and making it into a nap. He first weighs out, say an ounce ot beaver-down, a quarter of an ounce of musquash, and the same quantity of cotton wool. These three substances are placed on the bench in a heap, which might be covered with the palm of the hand. He then takes in his left hand a bow about seven feet long, which is also kept steady by means of a cord suspended from the roof, and gives repeated and sudden twangs to the string, using for this purpose a wooden pin with a projecting knob. At every vibration of the string on the tangled heap of fur, a quantity of the filaments spring up several inches, are carried a little to the right of the bow, and fall down within certain limits, in which they are detained by a wicker frame-work, called the *basket*, shaped like a fireguard, and set up with its concave surface towards the fur. By this process of bowing, all the fibres of the tangled mass are separated and equally distributed over a surface of several square feet in the course of a few minutes. The operation is repeated a second and third time, and such is the dexterity attained by the workman, that he seems able by the vibrations of his string to make the filaments fall into any required shape or position. When the fur is thus distributed into a large oval sheet, it is next pressed together so as to condense or *harden* it. The convex surface of the basket, and afterwards the hands, are employed to mat and interlace the fibres of the sheet of *napping*, as the fur is now called; and in order to complete the process, a skin of leather is interposed, and rubbed firmly with both hands, with a somewhat jerking motion, the skin being taken up and put down again in a different position several times. The use of this skin, called the *hardening skin*, tends to complete the interlacing of the fibres of the nap, and to produce a felt like thin flannel. The sheet of napping can now be handled with impunity. It is a long oval sheet, similar to No. 1 in Fig. 1126, and this is folded together, first sideways, as in No. 2, and then endways, as in No. 3, and is

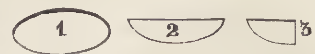


Fig. 1126.

measured while thus twice doubled, against the hat-body, or foundation on which it is ultimately to be placed. Hat-bodies are supplied to many of the town manufactories from provincial works which deal only in this article. They are commonly of wool, formed into conical caps, about fourteen inches high, and fifteen inches wide at the base. They are formed by the felting processes which come so largely under notice in this manufacture. If the sheet of napping, doubled as above, is deeper than the conical cap, or hat body, a portion of it is torn away and bowed again. From this waste a smaller sheet of napping is formed, and cut into strips for the brim of the intended hats, and for a thicker supply of nap to those parts which are most exposed to wear. At this stage of the operations,

Fig. 1127. HAT-MAKER'S BATTERY.

the workman proceeds to the hat-maker's battery, where, around an open iron boiler, there is accommodation for seven or eight men to work at a bench of

mahogany, sloping towards the boiler. This is charged with soft water, containing about half a gill of sulphuric acid, and beer-grounds, or a handful of oatmeal, the former assisting in the removal of unctuous matters from the wool or fur, the latter correcting, it is said, the corrosive tendency of the acid. The whole is kept at the boiling point by a fire below, and the workmen pursue their task amidst clouds of steam. The conical hat body is first held in the hot liquor, and when sufficiently soft is laid on the bench; a piece of beaver napping, sufficient to cover it, is gently laid on, the hat body is then turned over, and the napping, which is double, is unfolded and made to cover the other side also. The napping is sprinkled with hot liquor by means of a brush called a *stopping* brush, and is further worked with the hands, while hot liquor is occasionally poured into the body. Fresh nap is added from time to time, and that which is to form the under surface of the brim is put on when the hat body is turned inside out. A hair-cloth is next laid upon the bench, and upon this the napped body is rolled with a rolling pin, and worked in various ways by the hand, or rather by smooth pieces of wood covering the palm of the hand, and tied at the back with strings. These are called *gloves*.

The object of all these manipulations is the felting together of the nap and the foundation. When this is accomplished, and the roots of the fur have actually struck into the hat-body, the workman is immediately made aware of the fact, by the loosening and coming away of the cotton wool, of which it has been seen that a very small quantity was mixed with the fur at the commencement of the process. This cotton wool is incapable of felting, and, therefore, affords a valuable indication to the workman, by falling off when the other materials are felted, while in the previous stage it was of use in giving substance to the nap, and in effecting a saving in the quantity of beaver employed. Were the workman to continue rolling and pressing too long, the hairs of fur would pass completely through the hat-body and be found on the inside; therefore, it is important to know when to stop. Up to this point the napped hat-body still remains a loose conical cap, without any resemblance to a hat. But by pulling it and adjusting it with the hands, it is now capable of being drawn over a cylindrical block, on which it is tied with a cord. After much rubbing and pressing, the conical top is flattened into a crown, and the whole is adjusted to the shape of the block, while the brim, which is at first a puckered appendage, is also gradually worked into shape. The hat is now gradually dried in a hot room, and is afterwards made ready for dyeing, by first raising the nap by means of a carding-comb, and then cutting off the tips of the hairs so as to make them all of one length. This shearing requires a skilful hand, or the nap will be unequal or in furrows. It is done at one cut of the shears down the side of the hat, thus passing round and round the hat many times. The hats are further prepared for dyeing by being softened at a hot bath, called a *blocking-kettle*, and again drawn over wooden blocks.

When a number of hats (generally 5 dozen, called a *suit*,) have been thus prepared, they are hung on pegs within an iron cradle, and thus lowered, by means of a crane, into the dye-copper, Fig. 1128. Here they are immersed in a preparation of sulphate of iron, verdigris, and logwood, in water, forming a strong black dye. The cradle is allowed to remain in this dye, at a temperature of 180°, for about twenty minutes, when it is raised and left to drain for half an hour: this dipping and draining are repeated 13 or 14 times, until a bright glossy black has been obtained. The hats are now removed from the cradle to the blocking-kettle, the blocks are taken out, and the hats washed in 4 separate vessels of water, to remove any loose dye stuff; they are then put on a rack to drain, and lastly removed to the drying-room, which is heated to 160° or 170°, and where they remain on racks till the drying is complete. They are then subjected to a few finishing processes, the first of which is the picking out of coarse hairs by means of tweezers. Notwithstanding the care which is taken in sorting the down, there are always scattered hairs, which become conspicuous at this stage of the manufacture for their harsh and coarse appearance, and require to be removed. This being completed, the crown is next strengthened by inserting a piece of scaleboard, called a *tip*, on its under side, and pasting a piece of linen over it to keep it in place. A block is then put in, and the general surface of the hat is dressed and improved by means of warm and damp hair-brushes, hot irons, and a plush cushion called a *velours*, or *veluse*. If there are any refractory hairs which cannot be made to lie smooth by these means, they are burnt off by waving the hat rapidly through a large flame produced by shavings. The hat is then delivered over to women to be trimmed and bound, and to have the lining and leather sewed in; and, lastly, a superior workman finishes off the whole by blocking and setting up the hat in the most fashionable style.

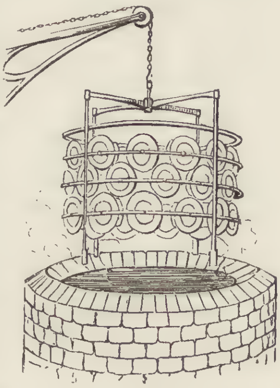


Fig. 1128.

One of the recent improvements in beaver hats consists of a hat-body of silk and a thin beaver *pull-over*, as it is technically called. The method of making the latter deserves notice on account of the felting process by which it is accomplished, and which may be taken likewise as a specimen of the mode of production of the woollen hat-body used in the ordinary beaver hat. The materials for the pull-over being weighed out and bowed, and the sheet of napping formed as before, the latter is at once made

into a conical cap, instead of being simply folded together. For this purpose a triangular piece of brown paper is damped, and placed upon the sheet of napping, which is folded over it, and completely covers and encloses it except at the base. Fig. 1129 shows the pull-over enclosing the paper; the dark shaded portion representing the woollen hat-body lying upon it. Any superfluous portions of the napping are removed, and are bowed again, and used to form the brim and thicken the parts requiring most strength. The brown paper remains within, while the cap is folded up in a damp cloth, worked about with the hand, pressed, bent, rolled and unrolled many times, whereby the fibres unite more closely. For a woollen hat-body a metal plate or bason is put within the cap instead of brown paper, the object being in each case to keep the sides of the cap asunder, otherwise they would felt together, and make a flat cone. On account of this the process is called *basoning*, even when paper merely is employed. The cap, thus formed, is twice as large as it will be when finished, for during the felting it shrinks greatly, and becomes thicker and more dense. The brown paper being removed, it is taken to the mahogany bench, sprinkled with hot liquor, and worked about in a variety of ways. It is then a perfect felted cap, and can be drawn over the silken hat-body, of which it forms the nap. The blocking is then performed as before described, the hat is dried and stiffened, and the after-processes are proceeded with as in the former instance.

Fig. 1129.

The manufacture of silk hats is less interesting than that of beaver, inasmuch as the felting process is altogether absent. The operations are, in fact, entirely different: no conical caps are made; no hat-maker's battery, or blocking-kettle, or dye-copper, is required. The hat-body is constructed on a block which consists of five pieces, forming, when put together, as in Fig. 1130, the oval shape of a hat. This block, being set up on a bench, a piece of calico is folded round the side of the hat, and the meeting edges are made fast by a solution of shell-lac. The whole of this layer of calico is then covered with cement, and another layer is then added and treated precisely in the same manner. The projecting edges at the top are then turned down upon what is to form the crown, and over it are cemented, in succession, three layers of calico, the last layer being also cemented on the outside. When these are all dry, a hat-body without a brim is produced. To make the latter, an oval piece of calico is cemented to a piece of twilled material, the latter being stronger and more absorbent of cement. The centre of this oval is cut away to suit the size of the hat, leaving a brim, which is secured to the hat by cementing one loose edge to the inside, and the other to the outside. A piece of calico saturated with cement is also bound, and ironed round the hat, to keep the brim firmly in its place: this is called a *band-robbin*. When quite dry, the proper width is given to the brim by means of a *rounding-brass*, or gauge, with notches, Fig. 1131, into one of which a knife is fitted, and in passing round the brim cuts off the superfluous portion. The hat-body is thus completed, and the method of covering it is equally simple.

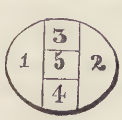


Fig. 1130.

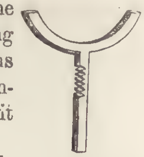


Fig. 1131.

The material for covering silk hats is a silk plush, woven like velvet in a loom with three treadles, and having a velvet nap or shag on one side. This fabric is manufactured in Spitalfields, and at Coventry and Banbury, but the chief supply is imported from Lyons. The plush is received in pieces of 20 or 30 yards long, and 26 inches wide, and great nicety is required in cutting it out, that none of the material may be wasted. It is cut into three distinct forms, namely, a circular piece for the crown of the hat, a rhomboidal piece for the side, and a long strip for the brim, rather wider than is sufficient to cover both its sides, and sewn together at the ends. The crown and side piece are sown together, so as to form a bag or cover to the hat, having a diagonal opening at the side. To put this on smoothly and well is a work of some dexterity. The calico hat-body, which is covered in every part with a layer of dry shell-lac varnish, is now rubbed with sand-paper to remove roughnesses. The strip for the brim is then fitted on, covering both surfaces, and being made to adhere by the application of a wet sponge, and then a hot iron, which act on the cement below, and make it hold fast the plush which is pressed down upon it. It is necessary to have both hands at liberty in the nice adjustment of the plush to its foundation, therefore a brass wire, attached to a rope stirrup, is made to embrace the hat just at the angle formed by the brim and the body; and this wire enables the workman to gather up all puckers in the upper cover of the brim, and cut away the superfluous portion above the wire. Fixing the remainder by means of the sponge and iron, he next adjusts the under surface of the brim, where the wire is evidently not available, but a brass plate, Fig. 1132, of a semicircular shape, let into the work-bench, answers a similar purpose in keeping the hat steady, and leaving the workman the free use of his hands. The superfluous portion of the plush is in this case not cut off, but turned up within the hat and secured to it. The plush-bag, or cover, has now to be drawn over the crown and sides of the hat, and adjusted so as to form a perfectly smooth surface. The diagonal line formed by the union of the parts is entirely concealed by the nap, but becomes visible in an old silk hat. Any fulness or tendency to pucker is drawn down into the band. Moisture and heat are applied as before to make the union of the parts perfect, and the surface smooth. A wire carding-comb is also drawn over the plush, which is further smoothed and made glossy by the application of a dummy

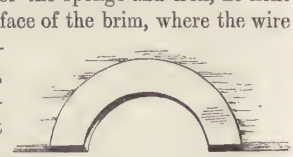


Fig. 1132.

of box-wood shaped like an iron, and of a velvet cushion.

The trimming and lining of these hats is performed by women, after which they are returned to the workshop to be tipped off, or shaped. A curl is given to the brim by the thumb and finger, after the part has been sufficiently softened by the sponge and iron. By holding the hat before a stove, the whole surface becomes soft enough to be moulded into any required shape: a hat-screw, then introduced, elongates the hat, while the shaping of the sides and brim can be easily performed by the hands. Imperfections in the nap are then removed by a steel picker, and the hat is polished and wrapped in paper for sale. So extensive is this manufacture at the present time, that for every beaver hat, it is calculated that 1,000 silk hats are fabricated.

We have not the means of furnishing the statistics of this important branch of industry at the present time. Some years ago England produced about 250,000 dozen of silk hats annually, of which more than half were fabricated in London. The annual value of the hat-manufacture, including beaver, silk, and wool-felts, is estimated at 3,000,000*l.* sterling. Many thousand dozens are exported, chiefly to the colonies. The beaver hat trade employs more subsidiary trades than the silk, on account of the preparation of fur, the making of long bows for the bowing process, &c.: the workmen also require a longer apprenticeship to learn the former than the latter trade.

Our notice of the hat-manufacture would not be complete without the mention of straw hats, which did not begin to form an article of British trade until late in the last century, although they were brought to great perfection in Italy more than two centuries ago. The importation of foreign goods having been interfered with by war, our own manufacture of this article rose into importance, and improvements in bleaching, plaiting, and finishing, as well as in the cultivation of indigenous grasses, were much encouraged by premiums from the Society of Arts. The straw of Tuscany, however, maintained its repute, and was plaited by our workpeople after the Italian method. This consists in first carefully sorting the straws as to colour and thickness, then selecting a certain number, frequently thirteen, and tying them together at one end. They are then divided into two portions, six straws being turned towards the left side, and seven to the right, so that the two portions of straw are at right angles to each other. The seventh, or outermost straw, on the right hand, is then turned down by the finger and thumb, and brought under two straws, over two, and under two. There are now seven straws on the left, and six on the right, therefore the outermost of the left hand straws is now to be turned down, and passed under two, over two, and under two again. The plaiting is continued in this way, alternately doubling and plaiting the outermost seventh straw from side to side, until it is used up. Another straw is then put in under the short end, in the middle of the plait, and by the crossing of the other straws over and under it, the fastening of it becomes secure. This kind of plait, shown in Fig. 1133, of about double the real size, is formed in pieces of great length, which are adjusted according to the Italian method, in spiral coils, to form large flats, as they are called, the edges being adroitly knitted together in the manner shown in Fig. 1134, which gives the plait, for the sake of dis-

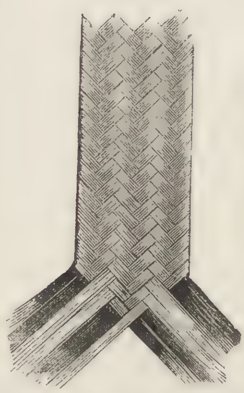


Fig. 1133.

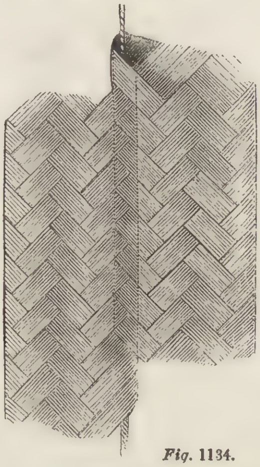


Fig. 1134.

tinctness, nearly four times larger than the real plait. The dotted lines show how far the angular folds or eyes of one piece are inserted into those of the adjoining piece. The thread which is run straight along in the interior is entirely concealed, and the join can only be detected by the slightly increased thickness of the plait. The best plaiters use the second finger with their thumb at their work, thus leaving the first finger free to turn the straws.

All the processes connected with the straw-hat manufacture, especially in warm climates, can be best performed in the spring, at which season there is also the largest demand for hats and bonnets of this material. The plaiting is much more perfectly executed in that temperate season than when the heat of summer has soiled, or the cold of winter has benumbed the fingers of the workpeople. No bleaching can effectually remove the tarnish communicated by warm and soiled hands, nor the tinge given in smoky rooms in cold weather. The large flats, above alluded to, are received in cases of from 1 to 20 dozen, varying in degrees of fineness. Names are given to the flats according to the districts which produced them. Florence is the principal market for the Italian hats.

British straw plaiting chiefly prevails in the counties of Bedford, Hertford, and Buckingham, but is carried on also in Essex, Suffolk, and other counties. When the straw is of British growth the process is as follows. The whitest and most regular straws are selected, and cut into equal lengths, then bleached by exposure to fumes of burning sulphur, and split lengthwise into several segments. To effect this a wire having four, six, or eight sharp edges is passed up the middle of the straw. The slips thus obtained are softened in water, and can then be plaited with great rapidity. The plait is passed between wooden rollers to make it flat and hard. The hat is formed

from it by winding the plait on a wooden block of the required shape in a spiral direction, leaving a little overlap, which is sewed to the part beneath. The seams are afterwards pressed down with a hot iron.

This domestic and healthful employment affords subsistence to a great number of persons, and usefully employs women and children whose labours could not otherwise be turned to so good an account. At the present time there are probably from forty to fifty thousand persons engaged in the manufacture. There are many varieties of plait in general use, known as whole Dunstable, split straw, patent Dunstable, or double seven, Devonshire, Luton plait, Bedford Leghorn, Italian plait, &c. There are also endless fancy plaits. Hats of Brazilian grass, bonnets of plaited whalebone shavings, and other curiosities of manufacture, also appeal to the love of novelty of purchasers.

HEALDS.—See Weaving.

HEARTH.—The flat or hollow space in a smelting furnace, upon which the ore and fluxes are submitted to the influence of flame. See Copper—Iron, &c.

HEAT.—In its ordinary sense the term heat is used to denote a quality otherwise called high temperature, the reverse of cold or low temperature. In a scientific sense the term heat or *caloric* is used to denote that substance or action which by its greater or less abundance or intensity in matter produces effects which are also expressed by the terms high or low temperature.

In all inquiries into the effects of heat, it is necessary to attend to the following rules respecting the application of the term temperature:—I. If a body subject to no pressure, or to a constant pressure, have at two different times the same bulk, it is said on both occasions to have the same temperature.

II. Two bodies are said to have the same temperature if, being kept in contact, the temperature of either remains unaltered by the action of the other.

III. When bodies of different temperatures are in contact, the temperature of the hotter body decreases and that of the colder increases, till they become equal.

IV. If the bodies be equal in mass or in weight, and of the same substance, the increase of temperature in one will be equal to its decrease in the other.

Hence it will be seen that differences of temperature are measurable and comparable with each other, quite independently of change of bulk; that is, without using the latter as a *measure* of temperature, but only as a *test* by which change of temperature is detected. In this way it has been discovered that the *same* increment (not *equal* increments, as from 40° to 50°, and from 50° to 60°) of temperature causes all masses of the same substance to expand in the same ratio to their whole former bulk; but this is by no means the case with different substances, as is obvious by looking at a common thermometer, an instrument for measuring changes in the bulk of a mass of liquid contained in a glass vessel of such a form, that changes, very small compared with the whole bulk of the liquid, may cause its surface to rise and fall through a considerable space. Now, this could not be done if the glass and the measuring scale, in undergoing the same changes of temperature as the liquid, experienced also the same change of bulk; for, if such were the case, the liquid surface would always remain opposite the same degree on the scale. The value of this simple instrument, therefore, depends on the fact—that liquids are more expansible than solids.

But it will further be seen that the ratio of the *change* of bulk to the *whole* bulk is different for every different substance, when the change of temperature is the same in all. It is necessary, however, to guard against a very common error respecting the relation between *temperatures* and the *numbers* by which they are represented; namely, the degrees of the thermometer.

Although the *differences* of temperatures are known and comparable quantities, yet their *ratios* are not so. We can compare them by addition and subtraction, but not by multiplication or division. We cannot say, "*This* temperature is so many times *that*," because we do not know the real zero of temperature; that is, we do not know what is the smallest bulk into which a given body is capable of being condensed by cold. We cannot, therefore, say, "*This* body exceeds its minimum bulk by twice as much as *that* body exceeds its minimum bulk;" or, in other words, "*This* body is twice as hot as *that;*" for although the temperature of one body may be 80°, and that of another 40°, these numbers are only reckoned from an arbitrary zero or starting-point, adopted because the real zero is unknown. But although we cannot say that A has twice the temperature of B, we can say that the temperature of A exceeds that of B by twice as much as the temperature of C exceeds that of D.

The first question, then, regarding the relation of expansion to temperature, is—"Do equal differences of temperature cause the bulk of a body to vary by equal differences?" This question had to be settled before it could be known whether the common thermometer (the scale of which is divided into *equal* parts) measured differences of temperature correctly. For this purpose, Dr. Brooke Taylor heated two equal weights of water, one to 200° and the other to 100°, and on mingling them together, he found them to indicate exactly 150°; thereby showing that equal differences of temperature cause equal differences in the expansion of mercury; or rather in the excess of its expansion over that of glass, which is clearly all that the thermometer can measure. More accurate experiments, however, have shown that this rule does not *exactly* apply to any solid or liquid, but only to *gases.* When equal masses of the same liquid, at different temperatures, are mixed, their combined bulk becomes a very little diminished. Liquids, therefore, instead of expanding by equal increments of space for equal increments of temperature, expand *faster* as the temperature increases *equably;* and it appears that the correctness of the mercurial thermo-

meter observed by Dr. Brooke Taylor was the result of a fortunate coincidence, by which the expansion of the glass, which is very small compared with that of the mercury, exactly compensated the increasing rate of the latter. This, however, would not be the case with thermometers constructed with other liquids, for their rates of expansion increase more rapidly than that of mercury. Hence spirit thermometers cannot be depended on for temperatures above the atmospheric range (or above 100°).

The rate of expansion in solids is also found to increase as they become hotter; but it is more equable than that of liquids. Instruments for measuring the expansion of solids are called *pyrometers* to distinguish them from thermometers, which measure the expansion of liquids and airs. The measurement of solid expansion is, however, by far the more delicate and difficult, not only from its smaller amount, but because we cannot measure at once the whole cubical increase or *expansion,* but only the increase of one linear dimension, that is, the *elongation* or *dilatation.* As solids do not in general alter their form by change of temperature, all the dimensions increase and decrease in the same ratio. The only known exceptions to this are afforded by *crystals.*

The first effect of heat on solids is expansion. If, however, the heat be more energetic, the solid is resolved into a liquid. The liquefaction of some solids is gradual; they pass through various degrees of softness; but in many, perhaps in most cases, there is no intermediate state between perfect solidity and perfect fluidity: the solid is heated up to a certain point, at which it remains solid; but a very slight increase of heat is then sufficient to liquefy a portion of it. Now, it is an important fact that the same substance always passes from the solid into the liquid state at precisely the same temperature, and this is called its *melting point* if it be above, or *freezing point* if below the medium atmospheric temperature. Thus the melting point of ice, or the freezing point of water, is 32° on the scale of Fahrenheit used in this country; but it is made the zero or 0° of the continental scales. The freezing point of mercury is about 70° Fahr. lower than 32°, and is therefore called −38° (minus 38°,) or 38° below zero, a degree of cold which in England can only be produced artificially. By the same means almost every other body that is liquid at common temperatures has been rendered solid. On the other hand, there are very few solids which have not been melted by artificial heat, or by that of the sun concentrated; and each one has its fixed and unalterable melting point. Thus, tin melts at 442°, lead at 594°, zinc at 773°, antimony at 812°, and so on.

But there are important circumstances to be noticed in the liquefaction of these bodies. It is evident that if a quantity of ice, at the temperature of zero, or 0°, be taken into a room whose temperature is 60°, the ice will begin to melt; and a thermometer placed in it, which at first indicated zero, will rise and soon reach 32°; but at this point it will remain stationary until the ice has entirely passed into the liquid form. Even if the vessel containing the ice be placed upon a fire, the mercury in the thermometer will not rise above 32° so long as any ice remains in the vessel. Now, it is obvious that, during this time, a quantity of heat must be constantly entering the vessel without rendering its contents hotter; for so long as this influx of heat is engaged in liquefying the ice, it produces no effect upon its temperature. Thus we see that increase of temperature is only one of the modes in which heat or caloric acts, and that when a portion of heat is producing the effect of *fluidity,* it cannot be at the same time producing the effect of *temperature.* The effect here described for ice applies equally to other solids. Hence we see that, during the process of liquefaction, a large quantity of heat disappears, or is *absorbed,* so as to be no longer sensible to the touch or to the thermometer. The heat thus lost is sometimes called the *heat of fluidity,* or *latent heat,* in contradistinction to the heat of temperature.

Another general effect of heat is the conversion of liquids, by an enormous expansion, into airs, gases, or vapours, as when water by boiling becomes steam. This effect is attended by the same important circumstance as in liquefaction, namely, the absorption or apparent loss of a large quantity of heat, which, however, reappears when the vapour is condensed again into the liquid form. A vessel of boiling water exposed to the atmospheric pressure of 30 inches maintains the constant temperature of 212°, and the most violent heat is insufficient to raise it above this point. The heat thus expended in vaporizing water without raising its temperature is sufficient to raise it no less than 970° if it were not vaporized; or, in other words, the latent heat of steam is nearly 1,000°.

Different bodies manifest different capacities for heat; that is, if two equal masses or weights, of the same temperature, receive the same amount of heat, they will not become equally hot, even although they do not change their state. For example, if a pound of mercury at 160° be mingled with a pound of water at 40°, the resulting temperature will not be the arithmetical mean, or $\frac{160+40}{2}=100°$; it will be only 45°; so that the 115° lost by the mercury heats the water only 5°. On reversing the experiment, and mingling a pound of water at 160° with a pound of mercury at 40°, the result will indicate 155°; so that the 5° lost by the water raises the mercury 115°.

Different bodies, therefore, have various degrees of susceptibility to heat. To produce a certain change of temperature requires a greater supply of heat in some bodies than in others. Numbers proportional to the quantities of heat necessary to produce the same change of temperature in equal *weights* of different bodies are called the *specific heats* of these bodies, or their capacities for heat. Thus, water is said to have thirty times more *capacity for heat* than mercury.

There are three methods by which heat is diffused, namely, by *conduction,* by *convection,* and by *radiation.*

Bodies that are kept in contact will (if of different temperatures) gradually change till they acquire the same temperature; that is, their shares of heat of temperature will become proportional to their capacities, and each body will have the same temperature throughout its mass. But this diffusion does not take place instantaneously, or there would be no such thing as difference of temperature. The rapidity with which heat travels varies in different substances. For example, if we place a silver spoon and a wooden one in boiling water, the handle of the former will become too hot to be held before that of the wooden one is sensibly warm. We see, then, that silver is a good conductor, and wood a bad conductor of heat. Different substances conduct heat at different rates. If we call the conducting power of gold 1,000, silver will be 973, copper 898, platinum 381, iron 374, tin 303, lead 179, marble 23, porcelain 12, clay 11. On placing one hand upon a piece of fur or flannel, and the other upon a piece of metal, both of the same temperature, (as they must be if left under the same circumstances,) and both colder than the hand, we call one warm and the other cold. This is an effect of sensation merely. The metal, being a good conductor, abstracts heat from the hand and gives the sensation of cold; the flannel or fur, being a bad conductor, not only takes away no heat, but allows it to accumulate, and hence the sensation of warmth. Precisely the contrary effect will take place if both bodies are warmer than the hand. The metal will feel hottest, and will even burn us, at a temperature at which the cloth would hardly seem warmer than in the former case.

But in liquids there can be no change of temperature without a displacement of particles. If heat be applied to a vessel of water, the particles near the bottom of the vessel being heated first and expanding, become specifically lighter, and ascend; colder particles occupy their place and ascend in their turn, and thus a current is established, the heated particles rising up through the centre, and colder particles descending at the sides, as shown by the direction of the arrows in Fig. 782, (article Ebullition.) This is evidently a very different process from conduction. The heat is not conducted from particle to particle without displacement, as in the case of a solid; but each particle, as fast as it receives a fresh accession of heat, starts off with it, and *conveys* it to a distance, displacing other and colder particles in its progress. This process has received the appropriate name of *convection*, and its importance will be seen if we apply heat to the *surface* of a liquid instead of to its base. Water being a bad conductor, we may boil it at the surface, while a lump of ice sunk to the bottom will remain unmelted.

Gaseous bodies, however, from the great mobility of their particles, are the most rapid conveyers, although (and, indeed, *because*) they are the slowest conductors of heat. Any body hotter than the air sets in motion an upward current of that fluid, which may be easily seen rising from bodies that are much heated, and the particles which rise are immediately replaced by the influx of other particles from every side. The slightest difference of temperature is sufficient to produce these effects, and hence the rapidity with which the air reduces all bodies to its own temperature. A body colder than the air, such as a lump of melting ice, produces an opposite action: it cools the air in contact with it, which, becoming denser, descends in a continual stream, supplied by an influx of air from all sides to the ice, until the whole is melted.

Actions of the same kind in the great scale of nature give rise to all the varieties of *wind*, by which the whole mass of the atmosphere is kept in motion, and its temperature so far equalized as to mitigate the extremes of climate, and render both the equator and the polar regions habitable. Such effects as these could not take place if the great ocean of air were heated (as at first sight it may appear to be) from above. The atmosphere receives scarcely any of its warmth directly from the sun's rays, but is heated almost entirely by the ground on which it rests, and is, therefore, in the condition of the water in a boiler, where the heat is applied from below.

But it is different with the liquid masses of our globe. The heat is applied to them at their surface, and is therefore not diffused by convection. It creeps slowly downwards by conduction, so that the temperature of all deep waters is found to diminish downwards. In the absence of the sun, however, the process of *cooling* goes on by convection; the surface waters being cooled first, become denser, and therefore sink, while new portions are brought to the surface, where they are cooled and sink in their turn; by which circulation the whole would very soon be reduced to the freezing point, were it not that the wisdom of the Creator has ordained that the general law of rarefaction by heat and condensation by cold shall, between certain limiting temperatures, be reversed. Thus water contracts by abstraction of heat down to about $39\frac{1}{2}°$, when it has attained its point of greatest condensation by cold; from this point to 32°, its freezing point, it expands by the application of cold. Hence the operation of this exceptional law gives rise (in water below $39\frac{1}{2}°$) to a species of convection exactly the reverse of that in other fluids, namely, a convection of heat more readily *downwards* than upwards. Thus, above the temperature of $39\frac{1}{2}°$ masses of water are more easily cooled than heated; and below $39\frac{1}{2}°$ they are more easily warmed than cooled.

The third method by which heat is diffused is by *radiation*, as when we stand at a distance from the fire, and experience its warmth. The heat is not, in this case, brought to us by any current of air, for that must set in *towards*, and not *from*, the fire; and besides, heated currents tend constantly to ascend. Nor can it depend on the conducting power of the air, for that is very slow indeed, and we experience the heat of the fire instantaneously. From these and various other reasons, it is evident, that a substantial medium, path or passage is not necessary for the propagation of heat.

If a red-hot cannon-ball be suspended in the air,

rays of heat will be emitted from it as a centre, in radial lines, which move with the velocity of light, and, like the luminous rays, may be reflected, absorbed, refracted, transmitted, &c., by encountering certain surfaces; and these rays may be reflected or transmitted without disturbing the temperature of the reflecting or transmitting bodies; but if the calorific rays be *absorbed* (that is, if they are stopped, and wholly or partly cease to exist as *rays*), an immediate increase in the temperature of the absorbing body is the result. This transmission must not be confounded with conduction of heat. The latter is always a slow process, while the transmission of radiant heat, or calorific rays, is instantaneous. It is the peculiar property of these rays, that they do not heat bodies through which they pass, as conducted heat must do. The worst conductors of heat (air and gases) are the best transmitters of these rays, while the best conductors (metals) totally stop the progress of the rays.

The intensity of radiant heat diminishes in the ratio that the squares of the distances from the radiating points increase; that is to say, the heating effect of any hot body (such as the red-hot ball above noticed) is nine times less at *three* feet than at one; sixteen times less at four feet; and twenty-five times less at five feet. Now, as this law applies to all influences that spread from a centre, such as gravitation, light, heat, electrical forces, magnetism, sound, and in fact all *central forces* when not weakened by any resistance, or opposing force, it is desirable to impress the law fully on the reader's attention by giving a reason for it. Suppose a board two feet square, Fig. 1135, to be held with its centre exactly

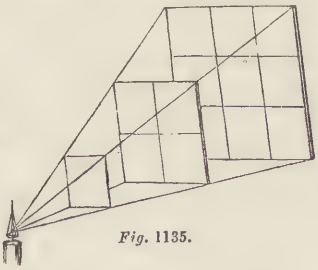


Fig. 1135.

two yards from a candle, and another board one foot square to be held parallel with the first board, and exactly half-way between it and the candle, it is evident that this will exactly intercept the whole of the light that would have fallen on the first board, and no more. But its area is only one-fourth of the first board. Hence we see that the same quantity of light which at *one* yard from its source covers *one* square foot, will, at two yards from its source, be spread over *four* square feet, and consequently be four times less intense. So, also, a board *one* foot square will intercept exactly all the light from another board that is *three* feet square, if the latter be three times as far from the candle; so that any portion of the latter board would receive only *one-ninth* as much light as falls on an equal space of the nearest board. Now, all this must plainly apply not only to light, but to any force that proceeds from a centre in straight lines or rays, and consequently to radiant heat.

All bodies, when raised to an equal temperature, do not radiate equal quantities of heat in equal times. It is, however, remarkable that the rate at which a body cools is influenced by the state of its surface more than by the nature of the material of which it is composed. A vessel covered with lamp-black and filled with hot-water will cool down to the temperature of the surrounding air almost twice as quickly as the same vessel with a bright polished surface. If we call the radiating power of lamp-black 100, that of writing paper will be 98, sealing-wax 95, crown glass 90, plumbago 75, tarnished lead 45, mercury 20, clean lead 19, polished iron 15, gold, silver, copper, and tin, all polished, 12. It has been proved that the same surfaces which radiate most quickly also absorb rays of heat most quickly; and it is remarkable that these two properties are exactly proportional in all bodies, or, in other words, the same numbers which express the relative radiant powers of any list of substances (as above) will also express their relative absorbent powers.

By absorption we do not here mean the conversion of sensible into latent heat; but the conversion of radiant into conductible heat. Not all the radiant heat, or rather the radiant effect, which enters a body is immediately *absorbed* or converted into heat: a portion continues its course through the body without warming it; and though more and more is absorbed at every step, yet if the body be not thick enough to absorb all the rays, some of them will emerge on the other side and continue their course till, by the warming of the various media through which they have travelled, all their heating effect has been expended and they cease to exist as rays. The speed with which this is effected is enormously different in different media. Those in which it takes place most slowly are called the most *diathermanous;* but no medium, not even air, is perfectly diathermanous, though a thickness of many miles of it absorbs less radiant heat than a small fraction of an inch of most solids. Hence the atmosphere is scarcely warmed at all by the sun's rays passing through it, their effect being produced on the ground or sea, which in its turn warms the air, by convection, which is a necessary process in the production of *winds.*

Not all the radiant effect which falls on the surface of a new medium enters it; a portion is always reflected. *Radiations* or effects which are propagated in straight lines only (such as light and radiant heat), are most conveniently considered by dividing them into innumerable straight lines or *rays;* not that there is any such division in nature, but to enable us, amidst the extreme complexity of these phenomena, to confine our attention to the simplest independent portion of the effect. Every individual ray, whether of heat or light, proceeds in a straight line until it meets a reflecting surface, from which it rebounds in another straight line, the direction of which is determined by the law that the angle of incidence is equal to the angle of reflexion, to which, however, in this case must

(on account of its generality) be added another condition, viz. that the *plane of reflexion*, as it is called, (or that imaginary plane which contains both the incident and the reflected ray,) is *perpendicular* to the reflecting surface at the point of contact. Thus, let a ray from A, Fig. 1136, fall on a reflecting surface at B. We must suppose a perpendicular to this surface erected at the point D, then the same plane P P, which contains both the incident ray and the perpendicular, will also contain the reflected ray B C, both rays making equal angles with this perpendicular B D, but on opposite sides of it. When the surface is curved, a perpendicular or *normal* (as it is then called) can equally be erected at any point of it; for it must be remembered that each mathematical point of such surface acts precisely as a tangent plane, that is, as a plane touching the curved surface at that point would act. Thence it happens, that certain regularly curved reflecting surfaces, called *mirrors* or *specula*, possess some remarkable properties. For example, if a mirror have the form of a *paraboloid*, any number of rays radiating from the point called its *focus* will be reflected into parallel directions, and any number of parallel rays coming to such a mirror are all reflected so as to meet in its focus.

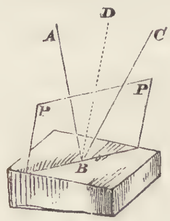


Fig 1136.

In Fig. 1137, two such mirrors, A and B, are shown.

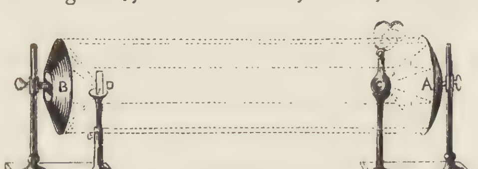


Fig. 1137.

They are made of metal, and highly polished, because we have seen that this kind of surface is the worst radiator, and therefore absorbs the least proportion of the rays that fall on it, and consequently must reflect the greatest quantity. If these mirrors be truly centered, that is, placed so that their axes may be exactly in the same straight line, and if a hot body be placed at C, in the focus of the mirror A, all the rays which it sends to that mirror will be reflected into parallel lines, and so reaching the other mirror B, will be reflected by it, and all brought to meet in its focus D, where a thermometer will be affected more than at any other spot, even though such other spot be much nearer the hot body C. Moreover, if a screen be placed either between C and A, or between B and D, the effect on the thermometer instantly ceases.

To render this experiment more striking, a red-hot iron ball is sometimes placed in the focus of one mirror, and some combustible, such as gunpowder, phosphorus, paper, &c., in the focus of the other. These bodies will be burnt, although their distances from the ball C may be 10 or 15 feet.

If, instead of a heated ball, we place in the focus of the mirror A a ball of ice, a thermometer in the focus of the mirror B will be observed to fall. When this experiment was first performed, it was supposed to arise from the *radiation of cold.* This, however, was a mistake; since no principle of cold, considered as a positive quality, can be admitted, cold being merely a sensation arising from the abstraction or diminution of heat; as darkness results from the absence of light, and silence from the absence of sonorous vibrations. In this experiment the thermometer sinks, because it radiates heat to the ball of ice. Hence we learn, that even a body at the ordinary temperature must be constantly radiating heat; and, of course, can only preserve its temperature by the counter-radiation it receives from other bodies. When two bodies are placed in the foci of the opposite mirrors, they are, as it were, isolated or cut off from any other source of heat, so that any heating effect observed in one must be derived from the other. The thermometer, therefore, in the last experiment, has a large proportion of its supply diminished much below its usual intensity, so that (its radiation remaining unaltered) its temperature must sink lower than usual.

These generalizations enable us to explain a still more remarkable instance of the apparent focalization of cold. If one of the parabolic mirrors be placed so that its axis[1] may point to the sun, as the rays coming from a body at so vast a distance are physically parallel, they will all be reflected to the focus of the mirror, so that it will act as a powerful burning mirror. But if the mirror be turned so as to face a portion of clear blue sky (the bluer and the nearer the zenith the better), its focus will become a focus of *cold,* and a delicate thermometer placed therein will sink, in clear weather, some degrees even in the day time, and as much as 17° at night.

Now, in order to understand this effect, it must be remembered that the thermometer is constantly radiating heat in all directions, and also receiving from surrounding bodies, in ordinary circumstances, just as much heat as it radiates. But in this experiment it receives less, because its usual supply from below is cut off by the mirror. But it may be asked, "Will nothing but a mirror serve this purpose?" Any other body would radiate from its own surface as much heat as it intercepts from other bodies; but a polished metallic surface, being the worst of radiators, supplies less heat than it intercepts. It must also have the form of a mirror, the focus of which must coincide with the place of the thermometer, because, if it had any other form, it would reflect to the thermometer some of the rays which it received from other bodies; but, because it is a paraboloid, it cannot reflect to its focus any rays except those that come in a certain direction, namely, parallel with its axis. Now, in that direction no rays come, for there is no body either to reflect or to radiate them. If a cloud, indeed, pass before the axis of the mirror, the thermometer rises to its usual height.

(1) The axis of a paraboloid, or of any mirror, is an imaginary line drawn from its centre through its focus, and prolonged indefinitely.

The following are some of the miscellaneous effects of heat:—

	deg.	
Measured by the Spirit Thermometer.	−135	Greatest artificial cold yet produced (Faraday). (Alcohol, ether, and sulphuret of carbon did not freeze.)
	−121	Carbonic acid (liquefied by pressure) freezes.
	− 58	Estimated temperature above the atmosphere (Svanberg and Fourier).
	− 55	Lowest atmospheric temperature observed by Parry. (Ross states it at −60°, and Back at −71°.)
	− 38·6	MERCURY FREEZES.
Measured by the Mercurial Thermometer	− 23	Greatest cold observed in Britain (Glasgow, 1780).
	− 7	Proof spirit (half alcohol and half water) freezes.
	− 4	Temperature observed at Greenwich in 1838.
	0	Nitrous acid boils under the common atmospheric pressure.
	3	Temperature observed at Greenwich, 1820.
	4	Saturated brine freezes.
	7	Spirits containing 25 per cent. of alcohol freeze.
	14	Oil of turpentine freezes.—Sulphurous acid boils (common pressure).
	20	Strong wines freeze.
	28·5	Sea-water freezes.—30° Milk freezes.
	32	WATER FREEZES, or ICE MELTS.
	36	Olive oil freezes.
	39·8	Water is condensed into its smallest bulk.
	50	Oil of aniseed freezes.—Mean temperature of England.
	52	Mean temperature of London.—Muriatic ether boils.
	70	Nitric ether boils under the common atmospheric pressure.
	81·5	Mean temperature at the Equator in America (83° in Africa).
	95	Highest atmospheric temperature observed at Greenwich, 1808; 91·5, in 1825; 90·2, in 1846.
	97	Pure ether boils under the common atmospheric pressure.
	98	Human vital-heat, or blood-heat.
	108	Phosphorus melts (and inflames in atmospheric air.)
	117·3	Greatest atmospheric heat observed by Burckhardt in Egypt.—Ditto, by Humboldt, in Guiana, &c.
	149	Wax melts (or becomes transparent).
	173·5	Pure alcohol boils under the common atmospheric pressure.
	201	The most fusible alloy of tin, bismuth, and lead, melts.
	212	WATER BOILS under the common atmospheric pressure.
	225	Saturated brine boils.—218° Sulphur melts.
	221	Heat obtained from the solar rays, by Saussure; (237°, by Robison).
	280	Saturated ley of potash boils under the common pressure.
	312	Oil of turpentine boils.—347°, Camphor melts, and boils at 399°.
	430	Sulphur re-solidifies.—442°, Tin melts.
	476	Bismuth melts.
	482	Sulphur melts a second time.
	554	Phosphorus boils.
	570	Sulphur boils (under common pressure).
	594	Lead melts.
	600	Linseed oil boils (under common pressure).
	620	Strongest liquid sulphuric acid boils (under common pressure).
	661	MERCURY BOILS under the common atmospheric pressure.
Measured by Daniell's Pyrometer.	735	Zinc falls to powder, and at 773° melts.
	810	Antimony melts. (*Red-heat visible in the dark.*)
	980	*Red-heat just visible in day-light.*
	1,140	Heat of a common fire.—1,500°, *Orange-heat.*
	1,869	Brass melts.—1,873°, Silver melts (*Yellow-heat.*)
	1,996	Copper melts —2,016°, Gold melts.
	2,786	Cast Iron melts (*White-heat*).
	3,280	Greatest furnace heat measured by Daniell. (Wrought Iron and Platinum did not melt.)
Not yet Measured.		Flame of the oxy-hydrogen blowpipe, Platinum melts.
		Galvanic current through air.
		Solar rays condensed by mirrors...... Gold boils.

We see by the instructive experiment mentioned at the bottom of p. 12, that every substance on the earth, however low its temperature, is constantly radiating its heat in all directions equally, and is also receiving heat in every direction except from the regions of space, or what we call the blue sky. After sunset, the supply of heat from the sun is withdrawn, but radiation still continues; and if there be no clouds to reflect back the heat, the temperature of the earth's surface soon sinks below that of the air which rests upon it, and the consequence is, a condensation of the moisture of the air by the colder earth in the form of *dew.* For the further consideration of this part of our subject we must refer to the article EVAPORATION.[1]

It appears from Mr. Joule's Experiments, undertaken with a view to determine the mechanical equivalent of heat,—1st, that the quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of force expended; and, 2d, that the quantity of heat capable of increasing the temperature of a pound of water (weighed in vacuo, and taken at between 55° and 60°) by 1° Fahr., requires for its evolution the expenditure of a mechanical force represented by the fall of 772 lbs. through a space of 1 foot.

HEAVY SPAR, a term applied to native sulphate of Barytes on account of its great weight, the sp. gr. being from 4·41 to 4·67. See BARIUM.

HECKLE. See FLAX.

HELIOSTAT, (from ἥλιος the sun, and the root στα to put or place,) an instrument, by means of which a solar ray admitted into a darkened room may be fixed in any desired position for optical experiments. It consists of a plane metallic mirror, provided with a vertical and horizontal movement, and of a clock, the index of which moves in a plane parallel to that of the equinoctial. The extremity of the index is connected with the hinder part of the mirror by means of a long cylindrical rod adjusted perpendicularly to the plane of the mirror.

HELIOTROPE, or BLOODSTONE. See AGATE.

HEMATINE, or HÆMATEINE. See LOGWOOD.

HEMP. A plant supplying a valuable and efficient material for cordage, and likewise every description of *canvas.* The latter word appears to be a corruption of *cannabis,* the Latin name of the genus to which hemp belongs. *Cannabis sativa,* or common hemp, has been cultivated in the East from a remote period, but not for its valuable fibres. The Orientals prepare from it an intoxicating liquor called *bang,* which serves both in India and Egypt as a substitute for malt-liquor. Hemp is also supposed to be indigenous in Europe, for so long ago as the time of Herodotus it was said to be growing wild in the country of the Scythians, and also to be cultivated for the fabrication of hempen cloth. In Russia and Poland the cultivation of hemp is carefully attended to at the present day, and the produce is of great importance in a commercial point of view: it is also

(1) This article is abridged from the Editor's "Introduction to the Study of Natural Philosophy," second edit. 1851. Published in Weale's Rudimentary Series.

cultivated in Italy, in the British isles, and elsewhere. America fosters this plant, but not to an extent to supersede importation. The hemp produced in England and Ireland is of excellent quality, but its cultivation has not been found generally profitable, and accordingly has been limited to a few districts.

The stem of this plant, as of flax, consists essentially of a woody core, surrounded by a sheath of fibrous matter, which is held together by a kind of vegetable glue. The appearance and growth of the two plants are, however, very dissimilar. Hemp belongs to the same natural tribe as the nettle, and has the coarseness of growth which characterises its relatives. It is an annual plant, some 5 or 6 feet high, with a rough and strong stalk, on which large leaves grow in pairs, on opposite footstalks, with two leaflets at their base. Some of the plants are flower-bearing, others fruit-bearing; the former being taller, more slender, and having finer and more elastic fibres than the latter. See Fig. 1138. It is impossible to distin-

Fig. 1138. HEMP.

guish this difference until the plants are nearly full grown, or to calculate on the preponderance of one or the other sort of hemp in the crop. The proportion of each, however, is generally pretty equal. On a rich moist soil hemp becomes coarse, but strong in the fibre; on a poor soil, it is slender and fine. If it be required for cables, hawsers, and other heavy rigging, it can scarcely have too rich a soil or too much manure; if it be wanted for weaving purposes, it should be sown broadcast on a poor soil. When sown and raked, or harrowed, it requires great vigilance to preserve it from birds, who have the utmost avidity for hemp-seed. It is a remarkable property of this crop that it scarcely requires weeding; on the contrary, the growing of hemp on a rank weedy soil is said effectually to cleanse it, so completely does it occupy the soil to the exclusion of all other vegetation.

In little more than three months the flower-bearing hemp has arrived at maturity, its flower fades, the farina falls, and the stem becomes yellowish. The fruit-bearing plants are not perfected until three or four weeks later, on which account there are frequently two separate gatherings of the crop. These are effected by pulling up the plants, cutting off the leaves, flowers and roots, and tying up the stalks in bundles. The next process is *retting* or *rotting* in water for the purpose of dissolving the vegetable glue which holds the fibres together. There are many objections to this practice, which is slow, uncertain, unwholesome and injurious to the fibre. "Hemp," says Professor Solly, "though from its coarser fibre less liable than flax to be injured by retting, is unquestionably often greatly deteriorated by the fermentation to which it is exposed; indeed in the old methods of preparing hemp, it was never considered to be retted enough until it was evidently injured. In illustration of this rather strange statement, let me refer you to Antill's observations on dressing hemp: he says, 'To know whether the hemp is rotted enough, take a handful out of the middle row, and try with both your hands to snap it asunder; if it break easily it is rotted enough, but if it yet appear pretty strong, it is not, and must lie longer till it breaks with ease.'" Some improvements have been made in the process of retting within the last few years, more particularly as it applies to flax, where warm water is used to expedite the operation; but the larger proportion of hemp-growers continue on the old methods to rot the stalks, either by letting them lie buried in snow, or exposed to the air and dew, or steeped in the water of ponds, or in that of running streams. The last named is mostly prohibited, on account of the poisonous properties attributed to the plant during putrefaction. The mode of retting as practised in Livonia seems one of the least obnoxious. Five or six basins about two feet deep are dug at different levels, where a fall of clear water is to be had; these basins are divided by slight banks made of clay, but communicate by means of a small hole in each basin, which can be plugged when required. The hemp is steeped in the lowest basin for two or three days, then in the next higher, and so on up to the highest, fresh plants being put in below as soon as there is room for them, the water in the top basin being at the same time renewed, and the holes unstopped so that a change of water takes place at the same time in all the basins.

When fermentation has proceeded far enough, the stalks are dried in the sun, or in ovens, or in warm rooms. They are then broken at a hand-break, or by mills, in the same way as flax, and the after processes of scutching and heckling are likewise similar.

The hemp trade of Petersburg figures largely in the commerce of that city. The hemp is brought to Petersburg from the interior beyond Moscow by water, and its quality varies greatly, according to the country in which it is produced. The great arrivals are in the spring

and summer, and the work of sorting it into qualities and making it up into bundles is performed by sworn agents called brackers, and by binders appointed by the government. To every bundle of hemp thus assorted there is attached a ticket with the names of the selector, binder and owner, and the date and year. Every bundle has also a piece of lead affixed to it, on which is stamped the selector's name on one side, and the sort of hemp and the time of selection on the other. The external marks of good hemp are its being of an equal green colour and free from spills; but its quality is further tested by the strength of the fibre, which should be fine, long, and thin. The best quality is called *clean hemp*, or first; the next, *out-shot hemp*, or seconds; then comes *half-clean hemp*, or thirds; and lastly, *hemp codilla*. This last is merely the part picked out in cleaning the other sorts. Of the first three sorts there are shipped at Petersburg every year about two million poods (sixty-three poods make an English ton), and the greater part of this is for the English and American markets.

In shipping hemp at Petersburg great care is taken to preserve it from wet, which would cause it to ferment afresh, and become totally spoiled. Every vessel taking in either hemp or flax is therefore provided with mats for its preservation. The hemp being light and bulky is forced into the hold of the vessel by means of winches, and thus made to occupy less room. The loading of a vessel is therefore rather a slow affair. Commodious warehouses have been built in Petersburg for the special purpose of housing hemp, and in these the greatest order is observed.

A very fine quality of Russian hemp is obtained from Riga, being brought down the river Dwina, from the interior, about the middle of May. This fetches a higher price than hemp from Petersburg. As a general rule, the prices of Russian hemp are highest in May, June, July, and the early part of August. In the month of September bargains may be obtained, many of the less opulent hemp-merchants being willing to sell their remaining stock at some roubles below the market price, in order that they may clear all out, and return to their own country to make new purchases for the ensuing year.

The quantity of undressed hemp imported into the United Kingdom in the twelve months ending May 1847, was 865,627 cwt. The quantity of dressed hemp amounted to 1,230 cwt., of which 171 cwt. was from British possessions, and all the rest from foreign countries. In the parliamentry returns, there are included, under the common title of *rough hemp*, several other substances besides the true *cannabis sativa;* for instance, several of those fibrous materials which attracted so much notice at the Great Exhibition, as Manilla hemp, Indian hemp, Jute, &c. The first of the three just named is commonly called Manilla white rope, and is obtained from the bark or epidermis of a species of wild banana (*Musa textilis*), which grows abundantly in the spice islands. Whole forests of this kind of banana exist in Mindaneo, one of the Philippines, and from it the natives fabricate both cordage and cloth. Indian hemp, or Sunn, (*Crotolarea juncea,*) is the fibre of a very different plant from our hemp, grown in different parts of Hindostan. Jute consists of the fibres of two plants, of the genus *Corchorus*, extensively cultivated in Bengal. It is mnch used in the great manufactures of Dundee, for the coarse fabrics used for bagging, &c.

English hemp, though well qualified by its strength and excellence for the manufacture of sailcloth and cordage, is seldom used for that purpose; but is principally made into the finer descriptions of hempen cloth, some of which can scarcely be distinguished, after they have become white by repeated use, from Irish linen. Excellent *huckaback* is made of it, for towels and common tablecloths; and a coarse cloth of great strength adapted for the shirting and sheeting used by labouring men. There are also varieties of superior quality and fineness, preferred by some gentlemen on account of their great strength and warmth, and possessing, besides these advantages, that of improving in colour the longer they are worn, whereas the reverse is the case with every other kind of linen.

HIDE, see LEATHER.

HINGE,—a joint of wrought-iron, cast-iron or brass, on which doors, lids, gates, shutters, &c. are made to swing, fold, open, or shut up. The usual form is that of two leaves, each furnished with a projecting segment or segments of a hollow cylinder, which fit together and admit of being united by a central pin. In applying this joint, one leaf is screwed to the door, and the other to the door-post, as is well known. The chief varieties are noticed in Hebert's Engineers' and Mechanics' Encyclopædia, as consisting of "*cross-garnets*, made in the form of the letter T, for gates and outhouse doors, from 6 to 36 inches long; and a nearly similar kind made with long straps and hooks to fix in the stiles, to enable the gates or doors to be lifted off their hinges at pleasure. Those used in common for the doors of apartments are termed *butts*, of which there are many varieties; those used for shutters are called *back-flaps*: similar hinges are used for the joints of bedsteads, and very nearly the same kind for Pembroke and other tables; another sort called H and H_ hinges, from their resemblance to these letters, are extensively employed for common purposes. There are also many other sorts, distinguished by appellations that designate their uses, and are too numerous to mention." The chief manufactories are at Birmingham, Wolverhampton, Tipton, and several parts of Staffordshire; the best wrought-iron hinges are made in Lancashire, and the heavier sort at Newcastle: there are also some excellent makers in London.

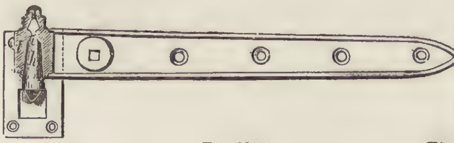


Fig. 1139

Fig 1140.

In Collinge's hinge, as improved by Redmund, the bearing pin consists of the conical stem *h* and the conical top *i*, Fig. 1140, corresponding with the

bearing socket of the hinge, Fig. 1139. Over this is a hollow cap fixed to the other limb of the hinge, the two parts fitting accurately; this cavity is for the reception of oil, and there is a small perforation to conduct it between the two surfaces, which work with great truth and freedom. This form is well adapted for turnpike gates.

Mr. Redmund's hinges are termed *rising butts;* that is, the hollow cylinder attached to the leaves, instead of being divided at right angles to the axis or pin *b*, Fig. 1142, are divided by spiral, or rather helical lines, so

Fig. 1141.

Fig. 1142.

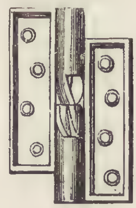


Fig. 1143.

that when the door is opened it is lifted up from the floor by the rubbing surfaces moving in a helical line upwards, so that although the door may shut close down upon the carpet, it rises when opened to a sufficient height to clear the carpet. Another advantage of this kind of hinge is, that the weight of the door acting upon the inclined rubbing surfaces causes it to close of itself; but provision is also made for causing the door to stand wide open when required: this is done by cutting away a portion of the helical curves, so as to form two horizontal planes which become opposed to each other when the door is opened to about an angle of 90°, or so as to form a right angle with its position when shut. By this arrangement, therefore, the door will close of itself when not thrown open more than 50° or 60°, which is as much as is required for free passage, but it will stand wide open if pushed as far as 90°. In this position a slight pull will cause the horizontal plane to slide off its support, and the door then returns by its descent on the helix. By the introduction of a small spring the door may be made to shut to closely when opened only a very little way. Hinges supplied with more powerful springs are used for the swing doors of public offices, &c., which are contrived so as to open either way, and to return quickly to their shut-to position.

In connexion with spring hinges, we may mention Mr. Hebert's contrivance for securing outside shutters

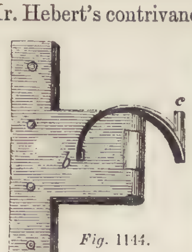


Fig. 1144.

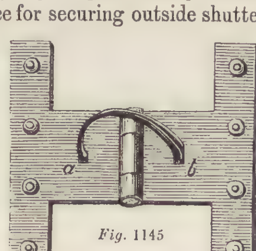


Fig. 1145

when thrown open. Fig. 1144, is the ordinary hinge shut, and Fig. 1145, the same open. A square hole is cut out at *a*, and a semicircular piece of iron *a b* riveted into it; a portion of the iron being split so as to form a spring, the extremity is turned upwards to form a stop, as at *c*. On opening the hinge the flap *b* passes over the arc, pressing on the spring, and when arrived at the stop *c*, it has passed the spring and is completely open with the shutter fastened flat against the wall. When it is required to close the shutter, the spring, which is close to the window, is to be pressed down to allow the flap *b* to come back over it; and when shut it appears as in Fig. 1144. This contrivance is only wanted on the lower hinge; it can be added for the additional cost of 6*d.* on a pair of hinges, and supersedes the troublesome turnbuckle, which fails to hold the shutter securely.

Whitechurch's patent hinge is so contrived as to allow doors, windows, &c. to be opened either to the right or the left hand. Nettlefold's hinge for book cases consists of a brass plate *a*, Fig. 1146, which is screwed to an upright partition, projecting from *a;* and cast therewith are the parts *b b*, the extremities of which are rounded off and perforated to receive the centre pin, which passes through them and the joint of the common butt hinge *c*, to the flaps of which are screwed the doors *d* and *e*. It will be seen that the door *e* folds back quite level with the bookshelves, and that the door *d* folds close against *e*, so as to be parallel with it and quite out of the way, so that the books close to the hinge can be taken out and put in without first disturbing the adjacent books, which is the case by the usual method of hanging doors to libraries. Now it is obvious that when the door *d* is turned back the contrary way, both doors are shut and lie flush and close, and that the door *e* may in like manner be folded over *d*. Thus great convenience is afforded by a single hinge, instead of two hinges, and the necessity for an additional hanging style is avoided.

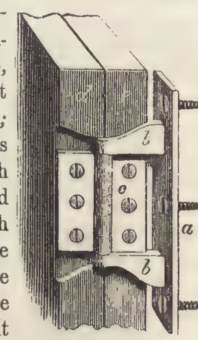


Fig. 1146.

A number of patents have been taken out of late years for improvements in the construction or manufacture of hinges. In Johnston's patent (sealed July 1839) the eyes of the hinge are formed out of one piece with the hinge plate, by forcing that portion of the metal of which they are composed into dies so shaped or formed as to turn over the metal into the form of eyes. For example, two plates of malleable or

Fig. 1147.

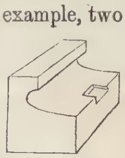


Fig. 1148.

Fig. 1149.

ductile metal are first stamped out, as shown in Fig. 1147: the projecting pieces or tongues are then forced into and against the concavity of the die, Fig. 1148, by which the tongues conforming to its curve become bent flatwise in their whole length, or so as to bring

the ends over to their own surface or to that of the plate to which they belong. See Fig. 1149.

Wilkes's patent (1840) is for manufacturing hinges by casting the two sides or flaps, and hinge joint thereto, at one time, on to a suitable axis.

Horne's patent (1840) is for an improved method of preparing the strips or plates of iron for hinges, so that the fibres of the metal shall be laid or placed crosswise of the hinge; secondly, for an improvement in making the joint, and for countersinking the screw-holes by means of coned dies.

Redmund's patent (1842) is for the construction of each of the flaps and its knuckle-joint-piece of rising hinges of one piece or casting; for a method of casting gate or such like hinges in such a manner as to obtain strength with lightness; also for a mode of constructing spring hinges, the knuckle-joints being made hollow to receive a compound coiled spring within a hollow axis. Instead of coiling a single wire into a spring, as is usually done, the inventor coils two, three or more wires side by side into a spring, by which means he obtains powerful springs in the same compass as that occupied by a spring of like diameter of one coil of wire, and which would of course be of much less strength. Figs. 1150, 1151, and 1152 give different views of this hinge: *j*, *k* are the two flaps; *l* a spring of two wires placed within the tube *m*, such tube being the pin or axis of the knuckle-joints of the hinge; *n* is a pin or stem within the spring, and fastened in the two ends of the caps of the knuckle-joints.

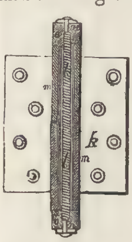


Fig. 1150.

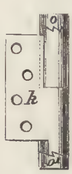


Fig. 1151.

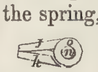


Fig. 1152.

The caps *o o*, have each a two or more threaded female screw formed therein to correspond with the spring used, and according as these caps are screwed up tightly so will the pressure of the spring be regulated, there being ratchet teeth to hold the caps, which allow them to be turned each in one direction, but resist their turning back. The last part of the patent is for a door hinge, which opens in either direction. Fig. 1153 shows the

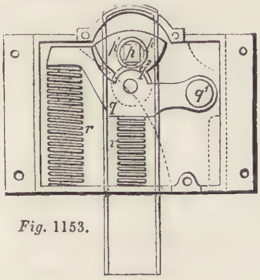


Fig. 1153.

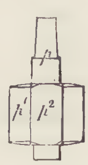


Fig. 1154.

plan of this hinge, and Fig. 1154 the axis for carrying the door. On this axis is fixed the cam p', in which at q^2 is a recess for the reception of the pressing lever. When the door is shut, q is a lever moving on an axis at q', and it carries a friction-roller q^2; a constant pressure is kept up against this lever by the springs *r r*.

Gollop's patent (January 1845) is for improvements in spring hinges and spring roller blinds. Instead of cylindrical springs of wire, a coiled flat bar or ribbon of steel is used. The arrangements are ingenious, and admit of extensive application.

Wilkes's patent (April 1845) is for forming the knuckle-joints of hinges without flaps by casting or otherwise separately, and then having combined them on axes and placed them in suitable moulds, to cause the flaps to be cast thereto.

Boydell's patent (November 1845) is, 1, for a mode of casting iron and brass hinges, the pivots or axes of the knuckles of the hinges being of one piece with one of the flaps of a hinge; 2, for a mode of casting brass hinges where separate pivots or axes are applied after the flaps of a hinge are cast; 3, for a mode of making cast hinges, casting the flaps of hinges several at one time, and in one piece, and then dividing them afterwards; 4, for a mode of annealing hinges.

HIRCINE, a peculiar fat obtained from the goat.

HONE, or HONE SLATES, a term applied to various slaty stones, which are used in straight slabs for whetting or sharpening the edges of tools after they have been ground on revolving grindstones. Mr. Knight, in his paper in the 50th volume of the Transactions of the Society of Arts, has enumerated the principal varieties. These are as follows:—1. *Norway ragstone*, the coarsest variety of the hone slates. It is largely imported from Norway, in the form of square prisms, from 9 to 12 inches long, and 1 to 2 inches in diameter. It gives a finer edge than the sandstones, and is in very general use. 2. *Charnley Forest stone* is one of the best substitutes for the Turkey oil-stone, and is used by joiners and others for giving a fine edge to various tools, and also to penknives. It is found in Charnwood Forest, near Mount Sorrel, in Leicestershire. The best variety is said to come from the Whittle Hill quarry, the other stones in the neighbourhood being more *pinny*, *i. e.* presenting hard places. 3. *Ayr stone*, *Scotch stone*, or *snake stone*, is used for polishing marble and copper plates; but the harder varieties are used as whetstones. These stones are always kept damp or even wet, to prevent them from becoming hard. 4. *Idwall* or *Welsh oil stone* is similar to No. 2, but generally harder. It is obtained from the vicinity of Llyn Idwall, in the Snowdon district of North Wales, and is more generally used for small articles of cutlery than No. 2. 5. *Devonshire oil-stone*, from the neighbourhood of Tavistock, is described as an excellent, but little known, variety, for sharpening all kinds of thin-edged broad instruments, as plane-irons, chisels, &c. 6. *Cutler's green stone*, from the Snowdon mountains of North Wales, is of so hard and close a texture as to be applicable only to the purposes of cutlers and instrument makers, for giving the last edge to the lancet and other delicate surgical instruments. 7. *German Razor hone* is known and esteemed throughout Europe as the best whetstone for the finer descriptions of cutlery. It is almost exclusively used for razors; for being very soft, it is cut by an instru-

ment applied at an angle, instead of being laid down flat as the razor is. This stone is obtained from the slate mountains near Ratisbon, where it occurs in the form of a yellow vein running into the blue slate, sometimes not more than an inch in thickness, and varying to 12, and in some places 18 inches; from whence it is quarried, and sawed into thin slabs, which are usually cemented into a similar slab of the slate to serve as a support. That which is obtained from the "old rock," or lowest part of the vein, is esteemed the best. 8. *Blue polishing stone* is a dark slate of uniform character, and not laminated in appearance. It is used by jewellers, clockmakers, and other workers in silver and metal, for polishing off their work. It is cut into lengths of about 6 inches, and from $\frac{1}{4}$ inch to 1 inch or more wide, and then packed into small bundles containing from 6 to 16 in each, and secured by withes of osier, in which state it is imported for use. 9. *Grey polishing stone* is similar in properties and uses to the *blue*, but somewhat coarser in texture, and its colours are paler. It is obtained from the same locality. 10. *Welsh clearing-stone* is a soft variety of hone slate cut in a circular form, and used by curriers for giving a fine smooth edge to their broad straight-edged knives used for dressing leather. 11. *Peruvian hone* has been recently introduced as a whetstone, and is said to come from South America. It cuts freely with oil or with water, and is suitable for sharpening large tools that do not require a very fine edge. 12. *Arkansas stone*, from North America, is of unequal texture, and cuts slowly. 13. *Bohemian stones* are imported from Germany, and are used by jewellers in the same way as Nos. 8 and 9, for polishing small work, such as the settings around gems. They cut well, and keep a good point for small work.

In addition to the above, we may here notice the *Turkey oil-stone*, although, from the absence of lamellar or schistose structure, it can scarcely be considered as a hone slate. Mr. Holtzapffel remarks, that "as a whetstone it surpasses every other known substance, and possesses in an eminent degree the property of abrading the hardest steel, and is at the same time of so compact and close a nature as to resist the pressure necessary for sharpening a graver or other small instrument of that description. Little more is known of its natural history, than that it is found in the interior of Asia Minor, and brought down to Smyrna for sale. The white and black varieties of Turkey oil-stone differ but little in their general characters; the black is, however, somewhat harder, and is imported in larger pieces than the white. The rough irregular pieces of oil-stone scarcely ever exceed about 3 inches square and 10 inches long, and are generally about one-third smaller. When cut into rectangular forms, it is done with the lapidary's slitting-mill and diamond powder. The blocks are then rubbed smooth with sand or emery on an iron plate. The piece of oil-stone is generally inlaid in a block of wood, in which it is cemented with the putty used by glaziers, and to avoid the deposition of dust, a wooden lid is usually added. The lid is sometimes covered with a thick piece of buff leather, which serves to absorb the oil from the tool, and is used in the manner of a razor-strop." Sperm or neat's-foot oil, or an oil not disposed to thicken, should be used.

Many persons find it difficult to use the hone in setting their razors, and are quite unable to produce the exquisite edge which cutlers give. For such persons, Mr. Fayrer's swing hone may be useful. It consists of a flat and parallel slip of brass, *a*, Fig. 1155, formed like a hone, but with pivots at the end,

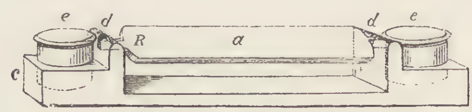


Fig. 1155.

by which it is mounted in two notches, *d d*, of a frame, *c c*, so as to swing and accommodate itself to the angle at which the razor or other instrument is applied to it. *e e* are two boxes, one to hold a coarse, and the other a fine, powder. One side of the brass, marked R, is first used with fine oil-stone powder and oil, afterwards the other side with pulverized water-of-Ayr-stone and oil, and the razor-strop is then resorted to.

Small pieces of this stone are cut into slips of different forms for the use of the lapidary and others. Oil-stone powder is also used for grinding together the brass or gun-metal fittings of mathematical instruments; and this powder is preferred to pumice-stone powder for polishing superior brass works.

The following are the analyses of a few polishing stones:—

	Alumina.	Silica.	Lime.	Iron.	Water.	Magnesia.	Carbonic Acid.
Polishing slate.	4·0	83·5	8·5	·6	9·0		
—	7·0	66·5	1·25	2·5	19·0	1·5	
Bohemian stone.	1·0	79·0	1·0	4·0	14·0		
Turkey hone.	3·33	72·0	13·33				10·33

In our article CUTLERY, we referred the setting of razors to the present article: we will therefore conclude with a few details on this subject. A razor may be defective from being *notched*, from having a *wire edge*, or a *blunt obtuse edge*. Notches arise from brittleness of the metal, occasioned by overheating in the forging or hardening. There is no remedy for this defect, unless, indeed, it has merely been left too hard in the tempering, when it may, perhaps, be remedied by tempering a little lower than at first. The wire edge in a new razor arises from the use of the glazers and polishers used in the manufacture. As these revolve away from, and not towards the edge, they always leave a thin filmy edge. The wire edge may also occur from the excessive use of the hone, "as when the two faces of the wedge are rubbed away beyond that point at which they first meet, a slender film of steel begins to form, because the extreme edge is then so thin, that it bends away from the hone instead of being rubbed off." The blunt obtuse edge is often occasioned by an excessive use of the strop, or after grinding, the hone has not

been sufficiently used. The rounded edge may occur from the use of a soft strop; the leather against the edge being indented, rises as an abrupt angle, and injures the keenness of the blade.

The whetstones used in setting razors should be perfectly flat on the face: they should be always supplied with oil, and be kept clean. In a new razor, or an old one just ground, the Charnley forest stone is used for striking off the wire edge. The Turkey oil-stone and the green hone, or Welsh hone, are also used; but the yellow German hone is to be preferred to all. Slabs of hæmatite iron ore are also occasionally employed for giving the final edge.

In striking off the wire edge "the blade is grasped in the right hand by its tang, and near to the cutting part, and is placed square across the one end of the stone, but tilted about 10° or 20°, and is then swept forward along the stone, edge foremost, in a circular arc, so as to act on the entire edge: each side in general receives only one stroke, and this produces a comparatively obtuse edge, measuring from 40° to 60°. Should this fail to remove the wiry edge, the blade is placed perpendicularly upon, and drawn with a little pressure across, a strip of horn, (generally a spoiled razor handle,) which is fixed down to the bench, the friction of the horn against the edge generally suffices entirely to remove the wiry film, otherwise the blade is struck once more on each side along the stone. Should the film of steel be left in the stone, it is removed before another blade is applied." The razor is then set on the German hone. It is held as before, but placed quite flat down so as to touch on the back and edge. "Some prefer a long sweeping stroke backwards and forwards, others prefer small circular or elliptical strokes, and others a short zigzag movement, but all gradually work from heel to point, or draw the razor forward so as to act on all parts alike, and most persons lift the razor endways towards the conclusion, allowing its point still to rest on the hone with the view of sharpening the circular end of the blade." The razor must be turned over at short intervals so as to whet it upon its opposite sides alternately; but it is usual "to conclude the process by sweeping the razor edge foremost once on each side steadily along the hone, as if in shaving off a thin slice of the hone: this lessens the disposition to the wire edge." The process must be continued until the new facets, constituting the wedge of 17° to 20°, exactly meet at the extremity of the more obtuse angle given by the striking off. Should the wiry film still form, it must be removed by drawing the blade across the slip of horn, and continue the whetting for shorter periods on each side. If the film is very minute, some persons leave it to be removed by the strop; but the hone must not be given up until the notches are no longer perceptible, and the edge, when viewed edgeways, does not present any visible thickness or width, but only the meeting of the two sides of the blade. The razor may now be slightly stropped, drawing it backwards from heel to point. The strop should have a hard surface, and only a very moderate quantity of abrasive matter; for if soft, and with a large quantity of dressing, the edge of the razor is very liable to be turned round. Mr. Holtzapffel recommends for the razor-strop a fine smooth surface of calf-skin, with the grained or hair-side outwards, pasted or glued down flat on a slip of wood. Almost any extremely fine powder, mixed with a little grease and wax, will do for the dressing, such as impalpably fine emery, crocus, natural and artificial specular iron ore, black lead, or the charcoal of wheat straw. The puffing advertisements and affected mystery of some strop-makers are unworthy the character of honest tradesmen. One side of the strop should be left plain for the finishing stroke, and the sheath, intended to keep the strop clean when not in use, should always be put on the same way, to prevent any of the dressing from being carried over to the plain side.

It is recommended by some to strop the razor immediately after use; others, on the contrary, advise that it should simply be wiped dry on clean wash-leather, or a soft towel, and not stropped until it is used again. We have tried both methods, and prefer the former. Although it is likely that many of the rules respecting razors are dictated as much by fancy as by reason, yet there does seem to be some grounds for the preference. In the operation of shaving we would recommend a cold lather for the face, the usual supply of hot water to be merely used for dipping the razor, which may be done once or twice during shaving, and again just before stropping. Now the effect of these dippings is to raise the temperature of the blade, and cause its edge to yield readily to the strop; then, during the repose of 24 hours, it cools down, and settles into that condition of edge which was imparted to it by the final stropping; and if this be skilfully and judiciously done, the razor is in prime condition when the time for shaving again comes round. If, on the contrary, the razor be dipped into hot water and stropped just before being used, the effect is too abrupt and sudden to allow of those molecular changes which we may suppose to take place on allowing the metal time to adjust itself on cooling down. But whatever course be adopted, one thing is certain—unless the strop be used with great moderation and caution, it is always likely to do more harm than good.

After the razor has been frequently set, it becomes so wide in the bevil or facet as to require re-grinding to thin it away. The cutler tries the keenness of the edge by making a faint incision in the thick skin, covering the inner edge of the palm of the left hand; he also tries it upon the thumb or finger-nail, placing it in a line with the finger, and obliquely across the end of the nail, or at right angles to the finger, allowing it to rest upon the back of the nail: the nail of the third finger is considered the most sensitive. In this way a very minute notch in the edge is quite perceptible: the keenness is also judged of by the degree in which the razor hangs to the nail, the keen blade making the deeper incision, and offering a dragging but smooth resistance, while the blunt razor slides over with less penetration and drag. Mr.

Kingsbury proposes the use of a magnifier for examining the entire edge. Under a microscope of a linear power of 50 to 100 the edge presents a faintly undulating and irregular line, resembling a ripple mark. Indeed, the edge of a good razor bears this severe scrutiny much better than most of the productions of art.

HONEY. See SUGAR.

HONEY-STONE, or MELLITE, a rare mineral, found in small solitary octohedral crystals of a honey-yellow colour, among the layers of wood-coal at Artem, in Thuringia. It contains an organic acid, the *mellitic*, (C_4HO_4,) and is in fact itself a mellitate of alumina.

HOPS. See BEER, vol. i. p. 113.

HORDEINE. See BEER, vol. i. p. 112.

HORN. The term horn is commonly applied to any hard projecting body on the head of animals, serving as a weapon of defence; but it is strictly applicable only to a certain class of such weapons. For instance, the antlers of the stag consist entirely of bone, and have no right to the denomination "horns;" the weapons of the ox, the sheep, and the antelope, consist of a sheath of true horny material on a bony core; while the horns of the rhinoceros are wholly composed of horny matter. Bone and horn are as distinct from each other as both are from ivory; yet the three are often confounded by the application of the general term "horn" to antlers, tusks, and true horns. Besides the horns on the head of animals, there are other horny processes in the hoofs, claws, nails, &c., and there are various modifications of horn, in the scales of the armadillo, the plate-armour of the tortoise, the spines of the porcupine and hedgehog, and the quills of birds.

Horn consists principally of membranous animal matter, being a compound of coagulated albumen, gelatine, and a small portion of phosphate of lime. It has been well remarked of these proportions, "had the horns much more earth, they would be brittle like bones; had they much more gelatine, they would be soluble like jelly or glue;" as it is, they are easily convertible to the purposes of the manufacturer, by whom they are so largely used that considerable importations of horns are necessary, in addition to the supply afforded by this country.

The horns chiefly applied to manufacturing uses are those of the bull and cow, with the hoofs of those animals. Large quantities are imported from Russia, South America, and Southern Africa. The horns of the bison and buffalo are also in demand, the latter being frequently reserved, on account of their beauty, for superior purposes. The horns of the chamois and antelope are polished and used in their natural forms.

The first process in the manufacture of horn is that of detaching it from the bony core: this is done by maceration of the whole horn in water for a month or six weeks, when the membrane which attaches the horn to the core is destroyed by putrefaction, and the two become easily separable. The cores, when burnt to ashes, form the best material for the small tests or cupels employed by the assayers of gold and silver.

The tips of the horn are then sawn off, these being entirely solid, and adapted for cutlery purposes, for the button-manufacture, &c. The remainder of the horn is then either cut into short lengths, or soaked entire, according to the use to which it is to be applied. Immersion in boiling water for half an hour greatly softens the horn, but the effect is afterwards heightened by holding it in the flame of a coal or wood-fire, when it becomes exceedingly soft, and can be easily slit up the side with a knife. It is now opened by means of pincers, and spread out nearly flat. In order to obviate the risk of scorching the horn over an open fire, Mr. James employs a sort of iron mould, with a conical iron plug. These are heated at a stove to the temperature of melting lead, and the horn cut lengthways with a saw or knife is inserted in the mould. The plug is then gradually driven in with a mallet, and in about a minute the horn is softened and ready to be opened in the usual manner. The "flats," as they are called, are then inserted either between iron plates, previously heated and greased, or between wooden boards, and are subjected to a certain amount of pressure, varying according to the intended use of the horn. If it is to be used in lanterns, the pressure is continued until the substance of the horn is separable into distinct plates. These are laid singly on a board covered with bull's hide, and scraped with a draw-knife, having a wire edge. When reduced to the proper degree of thinness, they are polished, first with a woollen cloth dipped in charcoal-dust and water, then with rotten-stone, and finally with horn shavings. The largest of the films of horn which come off during these processes, are often dyed and cut into various forms, when they become highly sensitive, and curl up by the mere warmth of the hand. Toys of this description were originally brought from China, hence they are commonly called Chinese sensitive leaves.

For general purposes the pressure given to horn is very moderate, especially for combs, where too much pressure causes the teeth to split. Heat and pressure applied to light-coloured horn, render it transparent; but artificial colour is given to the greater part of the articles fabricated of horn. This is easily done by boiling the horn in infusions of colouring ingredients. The rich red-brown, employed to imitate tortoiseshell, is obtained by mixing pearlash, quicklime, litharge, and a little pounded dragon's-blood, in a sufficient quantity of water. This preparation, after boiling half an hour, is applied hot to those parts of the horn which are to be coloured, and is left some time on the surface. A deeper tinge in particular parts is obtained by repeating the application. A blacker brown is produced by omitting the dragon's-blood.

For drinking-cups the horn is cut into lengths before it is softened, and when the scalding and roasting processes have been gone through, it is not slit, but placed while hot in a conical mould of wood, a conical wooden plug being also driven in, to press the horn to the true shape. When cold it is taken out of the wooden mould, and fixed by the large end to the mandril of a lathe, where it is turned and polished, and

a groove formed to receive the bottom. This is cut out of a flat piece of horn by means of a crown saw, and is dropped into the horn, and forced into the groove, the horn having been previously softened before the fire, enough to admit of the necessary expansion. Contracting as it cools, the horn fixes the bottom so firmly as to make it perfectly water-tight.

For knife-handles and other works where horn requires to be moulded, the process is as follows. The horn is first cut with a saw into convenient pieces, and then heated until soft enough to be pared and shaped with a knife into somewhat of the required form. The pieces are then pressed into moulds consisting of two dies, or pieces of metal having cavities sunk in them; these cavities to be either straight, curved, twisted, or engraved in any device, according to the pattern to be produced. This mould, with the horn enclosed, is placed in a clamp worked with a powerful screw, the mould and horn having been dipped in boiling water for a few minutes previous to being subjected to its action. After 20 minutes' pressure the work is ready for finishing, which includes scraping and buffing with Trent sand and oil, and afterwards with rotten-stone and oil. Horn is sometimes used by watchmakers as a vehicle for the application of polishing powders to flat works.

The ancient uses of horn include its conversion into bows, examples of which are still found in India and China; its use as a musical instrument, (the horn of the wild bull tipped with silver, and slung in a silver chain, having been the true bugle-horn of former times;) its employment in windows before the discovery of glass, and its conversion to purposes of defence, a complete suit of scale armour made of horn having been seen and described by Mr. Aikin, to whose Lecture on Horn, delivered before the Society of Arts, and printed in their Transactions, vol. lii., we are indebted for many of the above particulars.

HORNBLENDE, an essential constituent of certain rocks, as syenite, trap, and hornblende-slate. It occurs in black and greenish-black crystals and massive specimens: often in slender crystallizations, like actinolite, and in short thick crystals. Its dark colour is due to oxide of iron. Its composition is, silica 48·8, magnesia 13·6, lime 10·2, alumina 11·5, protoxide of iron 3·5, protoxide of manganese 1·15, hydrofluoric acid and water 2·2.

HORN LEAD. See Lead.

HORN SILVER. See Silver.

HORN STONE. A variety of rhomboidal quartz, used for grinding flints in pottery mills. It is called *chert* in Derbyshire.

HOROLOGY, (from ὥρα, an hour, and λέγειν, to tell,) is that branch of the useful arts which describes the action of the various machines used for the purpose of measuring time.

It is not easy to give a good definition of time. According to Locke it is "the consideration of duration as set out by certain periods, and marked by certain measures or epochs." According to Aristotle "our conception of time originates in that of motion; and particularly in those regular and equable motions carried on in the heavens; the parts of which, from their perfect similarity to each other, are correct measures of the continuous and successive quantity called *time*, with which they are conceived to co-exist. Time, therefore, may be defined—the perceived number of successive movements."

There is no doubt that the regular periodical movements of the heavenly bodies gave rise to the measurement of time and the present method of dividing it. The space between the rising and setting of the sun has always been called a *day*, and that between the setting and rising of the bright luminary, a *night*. The moment the sun attains his greatest altitude is called *noon* for that day; and the time from one noon to the next is called a *solar day*. These effects are produced, not by the motion of the sun, but by that of the earth: the circumference of the latter is divided into 360°, so that by turning on its axis each of these degrees is brought to the meridian once in 24 hours, and $\frac{360°}{24} = 15$: hence, as 15° pass under the sun during each hour, 15° of longitude mark 1 hour of time. Berlin is nearly 15° to the east of London, so that it is almost 1 o'clock in that city when it is 12 in London.[1] The space of time between two appearances of a fixed star in the same spot, with reference to some terrestrial object, is the period of the earth's actual revolution, without reference to the sun, and is called a *sidereal day*. This is divided into 24 equal parts, called *hours;* an hour into 60 equal parts, called *minutes;* and a minute into 60 *seconds*. The year, or one revolution of the earth round the sun, is divided into 365 equal parts or days, and forms what is called *mean* time; while time, as naturally divided by the apparent motion of the sun, is called *true* or *apparent* time.

The earliest instruments invented for the purpose of measuring time were *sun-dials*, and *Clepsydræ*. The principle upon which sun-dials are constructed may be readily understood by supposing the earth to be a transparent sphere, Fig. 1156, with 24 equidistant circles *a*, *b*, *c*, *d*, &c. marked upon it, all passing through the poles: then, as the earth turned round upon its axis N S in its daily motion, each circle would pass in succession under the sun, or, in other words, the sun would be in the *plane* of each circle; and as the axis of the earth is in the plane of all these circles, if such axis were represented by an opaque body, such as a rod of metal, its shadow would be cast on the concave half of each circle in succession at the end of every hour, or the 24th part of each revolution. But as the distance of the sun may be regarded as indefinitely great when compared with the size of the earth, any small transparent globe, with hour-circles marked upon it, passing through the poles, and with its axis parallel to the axis of the earth, would, if made to revolve regularly in 24 hours, present the same appearances as the earth

(1) This will explain some of the apparently marvellous statements which we see in the newspapers respecting messages transmitted by the electric telegraph. Thus, if a message dated 1 o'clock were sent from Berlin to London, and 30 minutes were occupied in its transmission, it would be received in London at 12·30, or half an hour by the clock before it had left Berlin.

on the above supposition: the shadow of the opaque axis N S would fall in succession upon the hour-circles. Now if this small globe be cut by a plane, A B, passing through its centre parallel to the

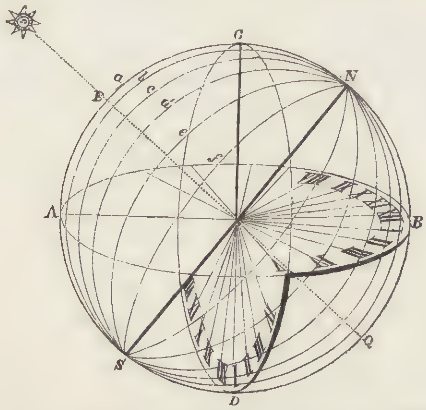


Fig. 1156. PRINCIPLE OF THE HORIZONTAL AND VERTICAL SUN-DIAL.

horizon of the place where the experiment is being conducted, and straight lines be drawn from the centre of the sphere to those points of the hour-circles cut by the horizontal plane; the shadow of the half axis above such plane will fall on those lines in succession every hour. In the construction of a sun-dial these lines are drawn by simple geometrical rules upon a flat surface supposed to represent the cutting plane A B; and a piece of metal, called a *gnomon*, with a sharp edge, called the *style*, is fixed on the surface, so that this style shall be truly parallel with the axis of the earth at the place of observation, then the shadow of this edge moves from one line to another in an hour. This forms the *horizontal sun-dial*. A *vertical* dial for fixing against an upright wall may be formed by cutting the globe with a vertical plane, C D, instead of the horizontal one, A B; in which case the planes of the circles will cut the upright plane in straight lines radiating from the centre of the sphere or of the circle; and the *lower* half of the axis will become the style of the dial.

The word *clepsydra* is from the Greek κλέπτω, to steal, and ὕδωρ, water, as indicating that the course of time was marked by the *stealthy* flow of water. If a vessel of water be kept full by a stream running into it, and a hole be made near the bottom, the water will flow from the hole and fill a second vessel at a uniform rate; and this second vessel may have its sides graduated, or carry a floating index pointing to a graduated plate divided into hours, and even minutes, provided the index rise fast enough to distinguish them. When the index arrived at the top it might be made to open a valve, let out the water, and descending to the bottom close the valve, and again commence its ascent: if it were contrived that this should take place every 12 hours, it would form a self-acting clock, requiring no aid except from the stream. But if a vessel be filled and graduated according to the rate at which water flows out, which is not uniform, but varies as the square root of the height above the hole at which it stands, this will also serve for a clock until the vessel is empty.

Hollow cups, with a hole in the bottom, were sometimes used to measure time: one of these being floated upon water would gradually fill and sink in an ascertained period. The burning of a *candle* or portions thereof also served the purpose of indicating divisions of time. *Sand* is in one respect preferable to water for measuring time: it flows through an orifice with very nearly equal velocity, because the pressure among its particles is not transmitted in all directions, as in the case of water. The *sand-glass* is so contrived, that a quantity of sand shall flow from one bulb of glass into another through a short tube or orifice connecting the two, in an hour, half-an-hour, or any other portion of time, and at the end of one period, another can be marked simply by inverting the glass.

All these contrivances for marking the course of time are so very inferior to the clock, that upon its introduction they were either superseded or retained as ornaments or curiosities. The invention of the clock is of much later date than some writers have supposed; for although the term *horologium* is met with earlier than the middle of the 14th century, the period assigned for the invention, that term was probably applied to all instruments used for marking the progress of time. The first clock is said to have been erected at Bologna in 1356. In 1364, Henry de Wyck, or Henri de Vic, a German artist, placed a clock in the tower of the palace of Charles V. The introduction of clock-work into England was probably in 1368, when Edward III. granted protection to three Dutch horologiers, who had been invited from Delft. About 1370 a clock was erected at Strasburg; about the same period Courtray had a clock, which was removed by the Duke of Burgundy in 1382. There was a clock at Spire in 1395; at Nüremberg in 1462; at Auxerre in 1483; and at Venice in 1497. By the end of the 15th century clocks were not uncommon in private families on the continent, and it is probable also that they had become general in England; for Chaucer uses the terms "clock" and "abbey orloge," in the way of familiar illustration. According to Berthoud, the clock, such as that erected by Henry de Wyck, is not the invention of one man, but of many men at different periods, and the following may be regarded as the principal steps in the invention:—1. The use of *wheel-work*, which was known and applied in the time of Archimedes. 2. A *weight*, used as a maintaining-power: this would probably be accompanied by a *fly* to regulate the velocity. 3. The *ratchet-wheel* and *click*, for winding up the weight, without detaching the teeth of the great or main wheel from those of the pinion in which they were engaged. 4. The regulation by a fly being variable according to the varying density of the atmosphere, &c. would lead to the invention of the alternating motion of the *balance*, and this would require an *escapement* of some kind. 5. These last two inventions would induce great regularity in the motions of the wheelwork, and would have suggested

the *dial-plate* with a single *hour-hand* or *pointer;* modifications, in fact, of the sun-dial plate and the gnomon: the *minute-hand* was a later contrivance, and the *seconds-hand* still more recent. 6. The *striking* part, to inform persons at a distance of the hour. 7. The *alarum*, or *alarm*, originally invented for the purpose of arousing the priest to his morning devotions.

Such appear to be the successive steps by which the clock attained a considerable degree of efficiency as a time-measurer. All great inventions are advanced towards perfection by a similar combination of the labours of many minds, and it may be taken for granted that De Wyck's clock was no exception to the general rule. One of the first applications of the clock was for astronomical observations, and we find that some of the most important improvements in clock-work are due to astronomers.

It is uncertain at what period the clock was made portable; but as early as 1530 it was proposed by Gemma Frisius to use a portable clock for the purpose of ascertaining the longitude at sea; and in 1544 the corporation of master clock-makers at Paris obtained a statute from Francis I., whereby any one not an admitted master was forbidden to make clocks, watches, or alarums, *large* or *small*. In making clocks portable, the substitution of a main-spring for a weight, as the maintaining-power, must have been made: this, with the invention of the *fusee*, introduced a new era into the art of horology.

The next great discovery in the art was the law of *isochronism of the pendulum*, made by Galileo while pursuing his studies at Pisa about the year 1581.[1] In 1583 he recommended the pendulum to be used in measuring time. In his first applications of it to astronomical observations he employed persons to count and register the oscillations, but he soon invented means for effecting this by machinery, and fifty years later he describes his "time-measurer," or pendulum-clock, "the precision of which is so great, and such, that it will give the exact quantity of hours, minutes, seconds, and even thirds, if their recurrence could be counted; and its constancy is such, that two, four, or six such instruments will go on together so equally, that one will not differ from another so much as the beat of a pulse, not only in an hour, but even in a day or a month." The honour of first applying the pendulum to a clock has been also claimed by Huyghens, who before the year 1658 certainly superintended the making of a pendulum clock, and whose excellent treatise "*De Horologio Oscillitacio*" led the way to many of the subsequent improvements in clock-work. He showed that the larger arcs of vibration of a pendulum occupy rather more time than the smaller, and that the time of a semicircular vibration is to that of a very small one, as 34 to 29. It should, however, be stated, that a countryman of our own is entitled to some share of the honour which has been contested by Galileo and Huyghens; for in 1641 Richard Harris made a long-pendulum clock for the church of St. Paul's, Covent-garden. It has however been suggested that Inigo Jones, the architect, having been in Italy during the time of Galileo, may have communicated to Harris what he had heard of the pendulum. Huyghens also constructed a marine-clock, and he discovered that its pendulum vibrated more slowly as its approached the equator, which led the way to the subsequent discovery of the oblate spheroidal form of the earth. He also discovered that the isochronism of the pendulum is true only when the ball moves in the involute of a cycloid; hence *cycloidal cheeks* were contrived for causing the ball to describe that curve; but as no substance could be found of sufficient strength and flexibility to form a thread which should easily wind on the cycloidal cheeks, and of such a nature as not to adhere to them, the cycloidal pendulum, although perfect in theory, was found to be inferior in practice to the common pendulum; for when this vibrates in very small arcs of a circle, its vibrations are, for all practical purposes, isochronous, because the circle has the same curvature as the cycloid at its lowest point, and may be taken as identical with it for a small distance.[2]

In 1676, a London clockmaker named Barlow invented the *repeating* mechanism, by which the hour last struck may be known by pulling a string. Much ingenuity was also thrown away upon the construction of clocks for showing both mean and apparent time. The most important invention of this period was the *anchor escapement*, the invention of which has been referred by some to Dr. Hooke,[3] and by others to Clement, a London clockmaker. "The great advantage of this escapement over the old crown wheel is, that it allows the escape to take place in a small angle of vibration, thereby preventing the necessity for the maintaining power acting upon the pendulum with so great a force as by the old plan; and by the introduction of a heavy ball, leaving that to be done by the uniform power of gravity, which before was dependent upon the impulse given by the wheel to the pallets. This change in the escapement introduced the practice of suspending the pendulum by a thin and flexible spring, another invention of Clement's; although this has also been claimed for Dr. Hooke. The seconds pendulum with this escapement was called the *royal pendulum*.

The next great invention in the art, was the introduction of the *compensation* principle for counteracting the effects upon the length of the pendulum of changes of temperature. In 1715, George Graham

(1) It is stated that the Arabs, as early as A.D. 1000, were acquainted with this property of the pendulum, and used it as a correct measure of time.

(2) The properties of the pendulum are stated at some length in the Editor's small work on Mechanics, published in Weale's Rudimentary Series.

(3) Hooke, having found that the real merits of pendulums had been obscured by making them vibrate in very large arcs, constructed in 1656 a clock which moved with astonishing uniformity: his pendulum was long and heavy, and was made to swing in very small arcs, and it is thought that he could not have attained to such a result, without a knowledge of the anchor escapement. Clocks on this construction were found to excel those with cycloidal pendulums; and Huyghens himself showed that the error of $\frac{1}{100}$ inch in the formation of the parts which produced the cycloidal motion would cause a greater irregularity than a circular vibration of even 10° or 12° could do.

substituted a jar of mercury for the pendulum ball, and thus succeeded in retaining the point of suspension and the centre of oscillation at the same distance from each other. Graham also suggested the idea of making use of the opposite expansions of different metals as a compensation for a pendulum; an idea which was realized by Harrison, who also introduced it into the balance wheels of watches, and succeeded in constructing a timekeeper which determined the longitude within such limits as to procure for him, in 1767, after much previous trial and inquiry, the parliamentary reward of 20,000*l*. Harrison also invented the *going-fusee*, by which a watch can be wound up without interrupting its movement.

It would be quite impossible within our limits even to notice the variations and improvements in clocks and watches which have been made within the last 50 or 100 years. Escapements alone have formed a theme for constant variation; and this is so favourite a subject, that almost every person of a mechanical turn has either made or planned some novelty in this way. Indeed, a celebrated clockmaker is reported to have said, that for a wager he would undertake to invent a new escapement every morning before breakfast.[1] It is, however, important to notice in this place the distinction between the *recoil escapement* and the *dead-beat escapement*. In the anchor escapement, already noticed, the pendulum vibrates some distance after the tooth has performed its office of impelling the pallet forward; the effect of which is to give a recoil or retrograde movement to the wheel, which may be noticed in the seconds hand of any common house clock. In such a clock this effect is of no great consequence, and as this recoil escapement is easy to make, it will probably continue in use. But for astronomical and other good clocks the recoil is objectionable as a source of error; Graham therefore contrived the dead-beat escapement, in which, however far the pendulum may swing, no recoil can take place. The *duplex* and *remontoire* escapements will be noticed hereafter.

Wooden clocks have been in use for about 200 years. They were first produced in Holland, and hence called *Dutch* clocks; but the manufacture has for a long time been mostly confined to the Duchy of Baden. Ornamental drawing-room clocks are still largely manufactured in France.

Dismissing historical details, we will now endeavour to lay before the non-professional reader a brief statement of the principles of horology.

It is a principle of mechanics that in every uniform motion, the spaces described are proportional to the times occupied in describing them. Such a motion is well adapted to the measurement of time, since it refers this measurement to that of the spaces described by the moving body. Hence in the construction of time-measurers the first thing required is the means of producing a uniform motion. But, in order that a machine may always move with the same velocity, the force which moves it must always be in equilibrium with the resistance which it has to overcome. If the resistance continue constant, the power will constantly act with the same intensity: if the resistance vary, the power must vary at the same rate, in order that equilibrium may not be disturbed. In the motion of a machine the number of resistances of various kinds is so great, and liable to such constant variation from changes in temperature, in moisture &c., that it does appear at first view extremely difficult so to arrange the power that it may be constantly in equilibrium with the resistances. In clock and watch work, these difficulties are rather eluded than overcome, as we shall now endeavour to explain.

The power employed to impart motion to instruments for measuring time, may be either a *weight* or a *spring*. This, in either case, is called the *maintaining power*.

In order that a weight may act as a maintaining power, it is suspended from the extremity of a cord which is coiled round a short cylinder moving on a horizontal axis, the other extremity of the cord being attached to the cylinder. See Fig. 1157. As the weight tends constantly to descend, it communicates a rotatory motion to the cylinder, which motion can be transmitted to the mechanism of the clock by means of a toothed wheel attached to the cylinder.

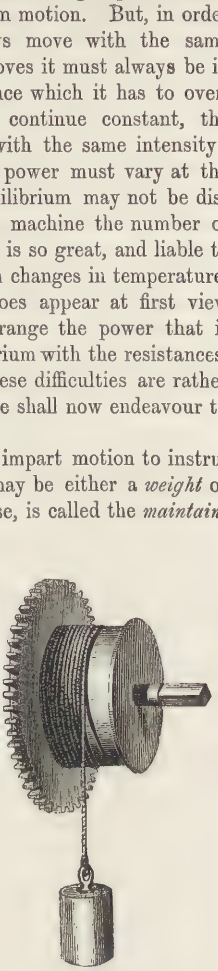


Fig. 1157

The springs employed as moving powers in timepieces, are long thin ribbons of steel, coiled up into a spiral form as in Fig. 1158. The outer extremity of this spring (called the *main-spring*) is attached to a fixed point, while the inner extremity is fastened to an axis, which being turned round in the proper direction, carries round with it the interior extremity of the spring, whereby the spiral coils are brought closer together, and the spring assumes the form of Fig. 1159. Now as the spring tends con-

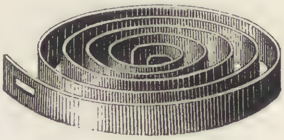


Fig. 1158.

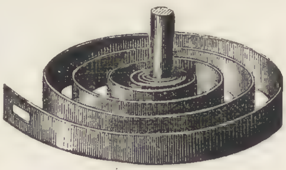


Fig. 1159.

(1) See Mr. Adam Thomson's "Time and Time-keepers," p. 147. The English appear to have monopolised the inventions in this important branch of the art. The inventor of the vertical escapement is unknown; the horizontal or cylinder escapement is by Graham; the lever escapement by Mudge, the duplex by Dr. Hooke, and perfected by Tyrer. The detached escapement, although invented by Berthoud, owes its accuracy to the improvements made by Arnold and Earnshaw.

stantly to uncoil or to assume its original form, it will in doing so cause the axis to rotate, and this rotatory motion is communicated to the mechanism of the clock or watch by means of toothed wheels and *pinions*. It is evident that this arrangement may be so far altered that the inner extremity of the spring may be fixed, while the outer extremity, being attached to a piece of mechanism capable of revolving round the axis of the spring, it would equally communicate a rotatory motion to this piece.

If we compare the action of the spring with that of the weight, an important difference will be discovered. The weight acts always with the same intensity, while the force of the spring goes on constantly diminishing from the moment when it begins to uncoil until it has reassumed its primitive form, Fig. 1158. The uniformity of action in the moving power, so necessary to the proper going of a time-keeper, is secured by employing a descending weight as in a clock, but where there is no space for a weight, or where portability is required, and a spring must be used as the moving power, its action is made uniform by an ingenious contrivance called the *fusee*. The spring is enclosed within a short cylinder A, Fig 1160, named the *barrel*, to the surface of which is fixed the extremity of an articulated chain B, which,

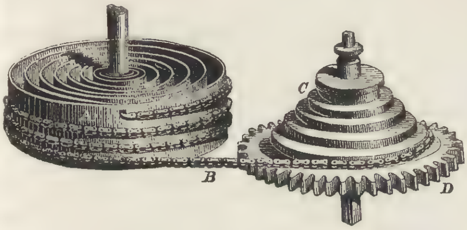


Fig. 1160.

after being coiled a certain number of times upon the barrel, is attached by its other extremity to the lower part of a conical piece C, called the *fusee*. This fusee is furnished with a helical groove for receiving the coils of the chain. When the spring is completely stretched, the chain exactly fills the grooves of the fusee, with the exception of the small piece which proceeds from the narrowest portion of the fusee to the barrel. The force of the spring in uncoiling, causes the chain to unroll from the fusee and to roll upon the surface of the barrel, and this action continues until the chain is completely detached from the fusee, except that small portion which stretches from the larger base of the fusee to the barrel. Now it is evident that during this motion the tension of the chain, depending as it does upon the force of the spring, goes on constantly diminishing; but as this tension acts upon the fusee at the extremity of a lever which gradually increases in length, the curve of the fusee has been so determined that there shall be an exact compensation; that is to say, the action of the chain produces the same effect as a constant force applied to the extremity of a lever of a constant length

It will therefore be understood that the fusee is a variable lever, upon which the main-spring acts through the medium of the chain. "A common observer would say of the fusee that it was a sort of cone, upon which the chain was wound from the barrel, by the operation of winding up the machine; but it is in reality a mathematical curve, which has this peculiar property,—that as the chain winds upon it, the distance from the centre of motion of the fusee to the semi-diameter of the chain which is in contact with it, continually varies; and also that it varies in this proportion, viz. that the distance of the centre of motion of the fusee to the semi-diameter of the chain, at that point where it leaves the fusee for the barrel, multiplied by the force of the main-spring acting on the chain at that time, shall be what mathematicians term 'a constant quantity:' that is, shall be the same whatever point of the fusee may be taken. Thus: suppose the chain which receives its power to turn the fusee from the main-spring pulls with a force of 9 oz., and that the distance from the centre of motion of the fusee to the semi-diameter of the chain at that part where it leaves the fusee is 42 hundredths of an inch, or expressed decimally, ·42; then $9 \times \cdot 42 = 3{\cdot}78$. Now let the spring be wound up to different points, at which its force will be respectively 12 oz., 18 oz. 20 oz., 30 oz., and 40 oz., the corresponding distances at which the chain must pull from the centre of the fusee will be respectively ·315, ·210, ·189, ·126, and ·0945 of an inch, for $\cdot 315 \times 12 = 3{\cdot}78$, $\cdot 21 \times 18 = 3{\cdot}78$, $\cdot 189 \times 20 = 3{\cdot}78$, $\cdot 126 \times 30 = 3{\cdot}78$; and $\cdot 0945 \times 40 = 3{\cdot}78$. Thus at any given distance from the centre of motion of the fusee, its power to turn any machinery is uniformly the same; and as the great or main wheel which communicates motion to all the rest in the watch or chronometer, is attached to the fusee, their centres of motion coinciding with each other, it follows that the power at the teeth of the main wheel is perfectly uniform."

The maintaining power, whether it be that of a descending weight or of a spring, is transmitted through a train of wheels and pinions. It first turns a central axis or arbor to which a spur-wheel is attached: the teeth of this wheel engage with, or lock into, the spaces between the teeth of a smaller wheel or pinion, which is fixed to a second axis parallel to the first: this second axis also carries a toothed wheel, which engages with a pinion fixed to a third axis, and so on. Now if the main-wheel, or that attached to the first axis, have six times more teeth than the pinion which engages with it, the second axis will evidently turn round six times quicker than the first; if the wheel of the second axis have four times more teeth than its corresponding pinion, the third arbor will turn round four times quicker than the second, and consequently twenty-four times quicker than the first. Thus it will be seen that the rotatory motion of the first axis is transformed into the rotatory motions of the second, of the third, of the fourth, &c., constantly increasing in velocity; and the relation between the velocities of two consecutive

arbors will be that of the numbers of teeth in the wheel or pinion which transmits the motion from one to the other.

Having thus given a general idea of the arrangement of the train of wheels and pinions in a clock or watch, and of the power which sets them in motion, we have next to show how this movement is regulated so as to cause the hour, minute, and seconds hands, to move uniformly over the surface of a dial.

It has been stated that in order to render the motion uniform, a permanent equilibrium must be established between the power and the sum of the resistances. For this purpose there may be attached to the last arbor of the train, or that which has the greatest velocity, certain pallets, which strike the air during their motion. They are of the form shown at *f f′*, Fig. 1161, and consist of a thin plate of metal, on two opposite sides of the axis with which they revolve. The resistance which the air opposes to their motion varies in proportion to the square of their velocity, the consequence of which is that when the motion begins to be produced, the resistance experienced by this *fly*, as it is called, is very small: the moving power is too great to allow of equilibrium being at once established, and the velocity of the whole train goes on increasing. But this increased velocity increases the resistance to the motion of the pallets, and the mechanism soon attains such a velocity that the power is in equilibrium with the resistances; the motion then continues uniform, and remains so as long as the power preserves the same intensity.

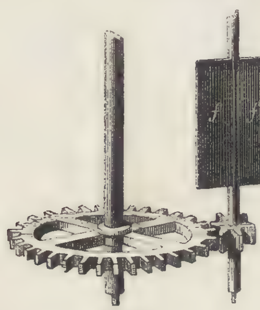


Fig. 1161.

There are, however, objections to this method of regulating the movement. The air which acts upon the fly is subject to considerable variations in density; moreover, the least change in the magnitude of the moving power, and in the friction of the different parts, disturbs the equilibrium, and, consequently, the *rate* of the whole mechanism. Hence the fly is not used where the precision of a clock is required. It is, however, used in the striking part of clocks, in musical snuff-boxes, in smoke-jacks, in Carcel lamps, &c., but in such cases the moving power is a spring which acts directly upon the train of wheels, so that although regular at any given moment, the rate goes on gradually diminishing until the spring has become quite relaxed, and all motion ceases.

As the means just indicated do not produce a motion sufficiently uniform for measuring time, a contrivance has been invented for producing not a continuous, but a periodically uniform motion. A piece of mechanism is made to oscillate in a regular manner, so that at each oscillation the whole train of wheels shall for a moment be stopped, thus producing an intermittent motion, and the hands which serve to indicate the time upon a dial-plate, instead of turning with one continuous motion, advance by a series of jerks; but each jerk passes over so minute a portion of space that the eye cannot distinguish it in the hour and minute hands, from an extremely slow continuous motion; in the seconds hand, however, this jerking motion is evident.

The piece which oscillates in the manner referred to, is called the *regulator*; the apparatus which connects the train of wheels with the regulator, and serves to arrest at each instant the motion of the wheel, is called the *escapement.*

The regulator employed in clocks and watches, consists of a metallic wheel, tolerably heavy at its circumference, moving upon an axis, to which it is attached at the centre. This wheel is called the *balance*; its oscillations upon its axis are of course produced by the maintaining power, the main-spring or the weight, transmitted through the train of wheels and the escapement. This will be evident from Fig. 1162, which exhibits at one view the several acting parts of a small portable time-piece, showing the connexion of the different parts. For the sake of clearness a few things have been omitted which will be explained separately, and the arbors or axes of the different wheels and pinions have been lengthened so as to remove the parts to a much greater distance from each other than is adopted in practice.[1]

A is the main-spring, the outer end of which is fixed to the base of the upright pillar; the uncoiling of this spring gives a rotatory motion to the axis *t*, to which it is attached at its inner extremity. This axis is furnished with a ratchet-wheel B, which acts upon the spur-wheel C, by means of the click *o*. The wheel C gives motion to a pinion D, and consequently to the wheel E, which in its turn moves the pinion F and the wheel G; the wheel G imparts motion to the pinion H, and the axis of this pinion causes the scape-wheel M to revolve by means of the crown-wheel K and the pinion L. The axis of the crown-

(1) Fig. 1162 is copied from Berthoud's fine old Treatise, entitled "Essai sur l'Horlogerie," 2 vols. 4to. Paris, 1763. We are also indebted to this work for several other figures. We have also consulted the splendid work, by the same authority, entitled "Histoire de la Mesure du Temps par les Horloges," 2 vols. 4to. New Edition, Paris, 1802. Also his "Traité des Horloges Marines," 4to. Paris, 1773, and the Supplement, 1787.

The reader interested in the subject will also do well to consult Thiout's "Traité de l'Horlogerie, méchanique et pratique," 2 vols. 4to. Paris, 1741. This treatise is illustrated with 91 large copper-plates, containing representations of the tools and engines used in making the works, and in general use by the clockmaker; together with abundant illustrations of the different parts of clocks, equation clocks, &c. Although a great part of the machinery here figured may be considered as more curious than useful, yet it cannot be said to have been unproductive. The inventive ingenuity thus constantly stimulated and exercised in the production of toys, produced also useful machines, and laid the foundation for the modern school of engineering, which have turned out such marvels as the Steam Engine, the Vertical Printing Press, and the self-acting Spinning-mule. When a man of genius is engaged, as George Graham was, in making a planetarium for the amusement of a nobleman, (Lord Orrery, whence these things are called *Orreries*,) he is also enriching mechanical science with new motions, and new combinations, which can afterwards be adapted to far more important purposes.

wheel turns with one end in a branch *c* of the *potence* I, and the other in the counterpotence J. Opposite the scape-wheel M, the teeth of which are cut in a particular manner, is the axis, or *verge*, of the balance N; this axis is furnished with two pallets *i i′*, placed at right angles to each other, and so arranged with respect to the upper and lower parts of the wheel M, as to fall into the teeth thereof in such a way that as the wheel rotates its teeth alternately fit into one pallet while the other is escaping therefrom. The pallet *i* receives an impulse which causes it to move from the front to the back; but soon the other pallet *i′* is in the path of one of the teeth of the wheel M, and receives an impulse therefrom which brings it into the front; whereupon the pallet *i* is again placed in such a position as to engage with the teeth of the wheel and is pushed into the front, and so on. To prevent the balance being carried round too far, two pins 1, 2, are placed upon it, and as soon as the vibration amounts to 120° they strike against a fixed tongue S, and are prevented from going any further. This is called *banking* the balance.

In the case before us the escapement is formed by the scape-wheel M and the two pallets *i i′;* and it is called a *vertical recoil escapement*, because each time that one of the pallets strikes one of the teeth of the wheel, the balance, which has not yet lost all its motion, causes the wheel to start back or recoil a small space. By employing the balance and the recoil escapement, the movement is not regulated in a manner altogether satisfactory. Each oscillation of the balance is communicated by the action of one of the teeth of the scape-wheel upon one of the pallets, and this motion is performed with greater or less rapidity, according as the pressure of the tooth upon the pallet is more or less intense. In the case before us, the force of the main-spring is constantly varying, as is always the case where no fusee is employed; the friction of the different pieces upon each other is also liable to variation, especially from the thickening of the oils used to lubricate them; these and other causes prevent the pallets from receiving the same impulse at different times, so that the successive oscillations of the balance are not of the same duration.

Fig. 1162 will also enable us to understand how the train of wheel-work causes the motion of the hour and minute hands upon the dial-plate. The axis of the wheel E is prolonged, and at its extremity is attached the minute hand. It is necessary, therefore, that the main-spring and the regulator be so arranged that this axis shall perform a complete revolution in an hour. On this axis is mounted a pinion P, which engages with a wheel Q, and the axis of the wheel Q carries a pinion R, which engages with a wheel S. This last wheel is attached to a hollow cylinder *b*, through which passes, with slight friction, the axis which carries the minute hand, and it is at the extremity of this hollow cylinder that the hour hand is fixed. In this way the two hands may have a circular motion round the same centre, and yet be moved at very different rates. The pinion P has 8 teeth, and the wheel Q 24; the minute hand, therefore, makes 3 turns, while the wheel Q makes but 1. On the other hand, the pinion R has 8 teeth, and the wheel S 32, so that the wheel Q makes 4 turns while the wheel S makes but 1; the wheel S therefore makes 1 turn while the minute hand makes 12, and, consequently, the hollow cylinder, which serves as an axis to the wheel S, gives to the hour hand its proper rate of motion.

The wheels and pinions, P, Q, R, S, with the hour and minute hands, are set in motion by the axis of the wheel E. Motion is communicated from this axis to all that part of the mechanism situated immediately below the dial, in such a manner that the hands can be made to move without turning the wheel E. For this purpose, instead of a single axis carrying the wheel E, the pinions D and P, and the minute hand, two axes are employed, placed end to end, one of which carries the wheel E and the pinion D, and the other the pinion P and the minute hand. One of these two axes is hollow at its extremity, and the other axis passes into this hollow with some amount of friction, so that when one of the axes is made to turn, the other will turn also unless it experiences a resistance capable of overcoming the friction between the two. When the wheel E turns, it moves the pinion P, and the hands also, which present only a feeble resistance; but, on setting the watch to the correct time by turning the minute hand, the axis of this hand does not in such case set in motion the axis of the wheel E, on account of the resistance offered by the whole train with which it is connected. The minute hand being moved causes only the wheels and pinions P, Q, R, S, to move with it, while all the other wheels continue stationary.

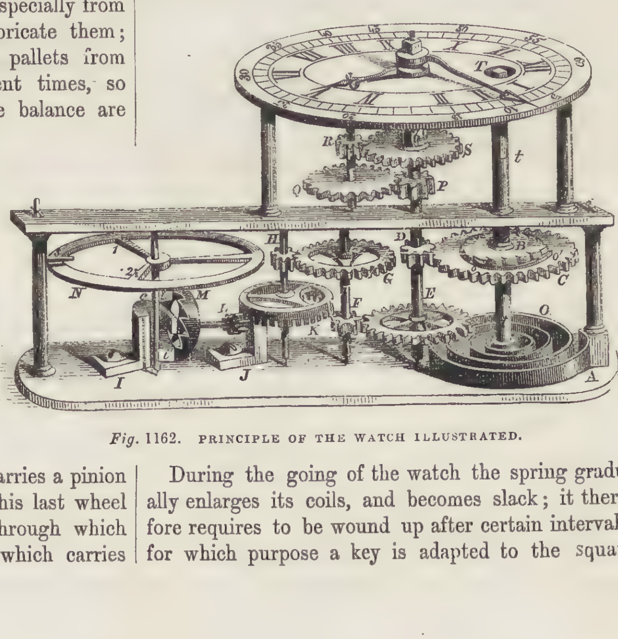


Fig. 1162. PRINCIPLE OF THE WATCH ILLUSTRATED.

During the going of the watch the spring gradually enlarges its coils, and becomes slack; it therefore requires to be wound up after certain intervals, for which purpose a key is adapted to the square

extremity T of the axis, to which the interior end of the spring is attached, and this axis is turned in a direction contrary to that in which the spring acts upon the train. If the wheel C were fixed to this axis, it would turn with it during the winding up, and thus impart to the whole train and to the hands a retrograde motion. To prevent this inconvenience, the axis of the main-spring is made to act upon the wheel C only through the medium of the ratchet-wheel B and a click *o*, which is kept in its place by the pressure of a small spring *o'*. By this arrangement the wheel C is moved by the axis only when the latter yields to the impulse of the main-spring; and when this axis is turned in a contrary direction, as in winding up the watch, it carries with it only the ratchet-wheel B, the teeth of which passing in succession under the click *o*, produces the sound so well known to every one who has a watch. Hence, during the winding up, the train of wheels and the hands remain stationary.

If the above description of the mechanism of an ordinary watch is well understood by the reader, he will have but little difficulty in following out those variations which distinguish a clock from a watch. The importance of a pendulum in regulating the movement of a clock has been already referred to. The escapement commonly employed for transmitting an impulse from the train to the pendulum is shown in Fig. 1163. It is called the *anchor escapement*, and consists of a piece of metal shaped something like an anchor, suspended from a horizontal axis, on which it can freely turn. Fig. 1163 shows the common form of anchor pallets, in which a tooth *a* is represented as having just escaped from the pallet A, and a tooth *b* on the opposite side of the wheel has dropped on to the pallet B. The pendulum will not, however, stop here, but will advance a little further to the left; and thus the slope of the pallet B will drive the tooth *b* a little way back, and produce the *recoil*. No particular form is required for such pallets. "Their acting faces are generally made flat, but they are

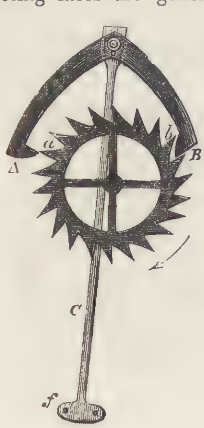


Fig. 1163.

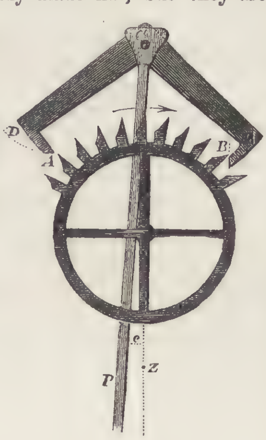


Fig. 1164.

better convex, as there is then less recoil and less wearing of the pallets by the points of the teeth. Strange as it seems that brass teeth should wear holes in steel made as hard as it can be tempered, it will always be found that the teeth have worn holes in these pallets after a few years, and the hole will be deepest towards the end of the place which the tooth reaches. It is evident that the tendency to make this hole will be less if the pallet is convex, than if it be flat." The recoil escapement is converted into a dead escapement,[1] Figs. 1163, 1164, "by making the slope of each pallet stop at the points A and B where the teeth fall, and making the rest of the pallets A D and B E portions of a circle whose centre is C, the axis of the pallets. For, in that case, however far the pendulum may swing, no recoil can take place. The reason why this escapement is so much better than the recoil escapement is, that a variation in the force of the clock train produces hardly any effect upon the time of oscillation of the pendulum, though it produces a considerable effect upon the extent of its oscillation." Although we cannot determine the proportion which the increase of the arc bears to that of the force, since it depends upon the varying friction of the different parts of the clock, yet they have a tendency always to correct each other; and when even the state of the clock is such that the arc increases just one-third as much as the clock-weight is increased, these two parts of the error will exactly counteract each other; but it generally happens that as the clock gets dirty the force and the arc decrease in such a proportion that the loss of time preponderates. But there is one case in which the opposite effect takes place, to the surprise of those who know the common result of a decrease of arc. Church clocks will often be found in a few months after they are put up to increase their arc of vibration considerably, and at the same time to gain. Mr. Denison discovered this increase of arc to arise chiefly from the decrease of friction on the dead part of the pallets, owing to the teeth and pallets polishing themselves more perfectly than had been done by the maker.

When a clock gains it is said to have a + daily rate of so many seconds, and when it loses, a — rate; but these signs are the reverse of those which indicate the decrease or increase of the time of an oscillation. The goodness of a clock is indicated, not by its rate, but by the variation in its rate.

The effect of the self-polishing of the pallets is only temporary; and the general effect of a decrease of force and space in a dead escapement is that the clock gains a little, whereas a common recoil escapement loses considerably as the arc decreases; and this has led to the adoption of a small recoil in the place of the dead part of the pallets. This recoil is given by striking the circle of the dead part of the pallets, not from the axis of the pallets, but from a point a little below that axis, in the line of centres of the pallets and the scape-wheel, which produces a circle of a higher degree of curvature, and, therefore, raises the teeth a little after they have dropped on to

(1) These two figures and the description are copied from Mr. Denison's valuable treatise on Clock and Watch-making, published in Weale's Rudimentary Series, 1850.

the pallets; and the further the pendulum swings, the greater is the degree of recoil. This is commonly called the *half-dead escapement*.

Another form of dead escapement, much used in the construction of turret-clocks, is called the *pin-wheel escapement*; it consists of pins set on the face of the scape-wheel, instead of teeth on its edge; the two pallets, instead of embracing about one-third of the circumference of the wheel, are put so near together as to leave room for only one pin to pass between them; and the end of one slope is situated just over the beginning of the other. The pins are half-cylinders: as the upper part of the cylinder could not act, the cutting it away allows the pallets to slip through close above the teeth, so as to waste as little drop as possible.

An escapement invented by Professor Airy and named the *duplex spring escapement*, is intended to prevent the inequalities of force of the train affecting the impulse on the pendulum. For this purpose there are two scape-wheels and two pairs of pallets, one for the stop and the other for the impulse: the stop-wheel is the one connected with the train, and the impulse-wheel rides on the same arbor, and is connected with the other by a spiral spring. The stop-wheel is let go by its pallets, which have no sloped faces, just before a tooth of the impulse-wheel would arrive at the slope of its pallets, and so the tooth is carried down the slope and the impulse given by the force of the spring only.

Escapements of this kind, in which the impulse is given to the pendulum by a small separate weight or spring, independently of the force of the train, are called *remontoir* escapements, because the clock train winds or lifts up the maintaining force at every beat, or at some given number of beats of the pendulum. Or to explain the matter a little more fully: In this form of escapement the impulses given to the pendulum are not imparted by the large going-train of the clock, which is exposed to variations of force and resistance from varying friction, from changes in the viscidity of the lubricating oil, from the effect of wind upon the large hands of the external dials (which in the Royal Exchange clock are each 9 feet in diameter); but the impulses are imparted to the pendulum by a small secondary train, set in motion by the descent of a ball or weight, which is itself raised at intervals of 20 seconds, by the mechanism of the going-train. In some cases a *remontoir spring* only is used for the purpose of setting the escapement in motion, it being itself wound up at very short intervals by the going-train, which receives its impulse from the prime mover. Now, as the velocity of the machine is determined by the escapement, so by detaching this from the power, whether a weight or a spring, which is always subject to some irregularity, a more accurate performance is ensured.

Fig. 1165 shows the method of connecting the anchor with the pendulum. The horizontal axis D to which it is fixed has attached to it a stem F, which terminates at its lower extremity in a horizontal fork or crutch G. The rod of the pendulum passes between the limbs of this fork, closely but not so tightly as to prevent the rod sliding within it when required, so that the pendulum cannot vibrate without the anchor vibrating also. The crutch C and the fork *f* are also shown in Fig. 1163.

In the recoil escapement, the weight is constantly acting on the regulator so as to modify its rate of going. In the dead beat, the influence of the weight is almost entirely removed, for it is exerted only in the friction of the teeth of the scape-wheel in the pallets, (which can be reduced to a very small quantity,) and in the impulses which the pallets receive from the teeth at the moment when they escape. If in addition to this we consider the isochronism of the pendulum, when vibrating in small arcs, some idea may be formed of the great accuracy to which clocks may be brought as measurers of time.[1]

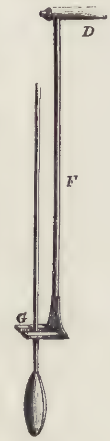


Fig. 1165.

The duration of each vibration of the pendulum, upon which the rate of a clock's going depends, is determined by the relation between the minute hand and the scape-wheel. The times of oscillation of different pendulums are as the square roots of the lengths of the pendulums. For example, if we take three pendulums whose lengths are as the numbers 1, 4, 9; then the times of vibration will be respectively as 1, 2, 3. That is, the pendulum whose length is 1, makes 2 vibrations to every 1 of that whose length is 4, and 3 vibrations to every 1 of that whose length is 9. For practical purposes this important law is expressed thus:—the times of vibration of different pendulums are in the same proportion as the square roots of the distances of their centres of oscillation from their axes of suspension. Now in order to regulate a clock so as to prevent it from going too fast or too slow, the bob of the pendulum admits of being screwed up or let down, so as to vary the distance between the centre of oscillation and the axis of suspension, or, in other words, to alter the effective length of the pendulum as required. When the clock gains, each vibration of the pendulum lasts too short a time: it is lengthened by letting down the bob through a small space. When the clock *loses*, the bob is raised, the effect of which is to shorten the effective length of the pendulum, and to cause it to beat more quickly.

Figs. 1166, 1167, show the arrangement of a clock which is regulated by a pendulum and an anchor escapement. The moving power or weight A, acts from the extremity of a cord, which is wound upon

(1) In order to ascertain how much of the first power of the clock is wasted in the friction of the train and pulleys, or how much a given escapement requires, remove the pallets and fix to the scape-wheel or its arbor an arm of any convenient length, and hang small weights to the end of it till the weight that the clock will just decidedly lift is found, the arm being horizontal. The arm should have a counterpoise and be as light as possible, so that its own weight may not enter into the question or add much to the friction of the scape-wheel pivots.

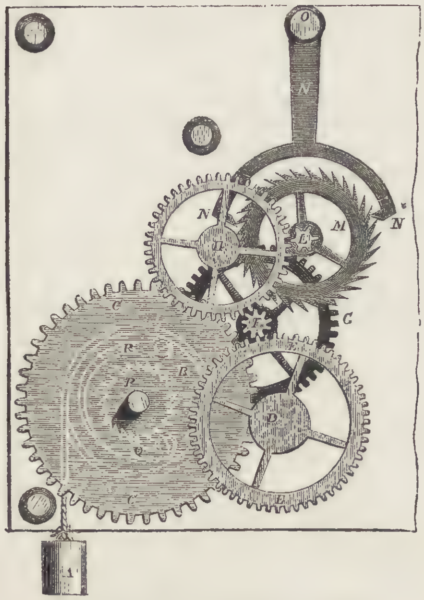


Fig. 1166. WORKING PARTS OF A CLOCK.

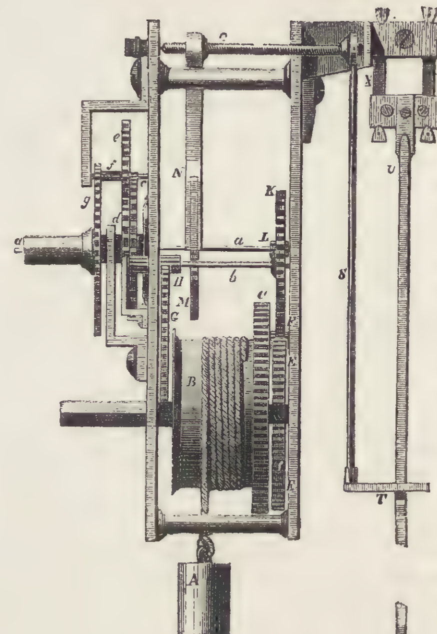


Fig. 1167. SIDE VIEW.

the barrel B, which it tends to turn round, and with it the wheel C. This wheel C engages with a pinion D, the axis of which carries a second wheel E. The pinion F engages with the wheel E, and upon the axis of F is fixed a third wheel G, which in its turn engages with the pinion H, upon the axis of which is the fourth wheel K; K engages with L, on the axis of which is the scape-wheel M. The anchor N N, moving on an axis O, encloses the upper part of the scape-wheel M. The axis O, Fig. 1167, carries a rod S, whose fork T embraces the pendulum rod U U, of which V is the bob. The pendulum is suspended by two pieces of steel spring X X, which bend in one or other direction, according to the vibration of the pendulum. "It is of great importance," says Mr. Denison, "that the real point of suspension of the pendulum, that is, the top of the spring where it begins to bend, should be kept firmly in the same place; for if it moves it will increase the time of vibration, since this is evidently the same thing as if the fixed or real point of suspension was a little higher up, or the pendulum so much longer. For this reason, in the best clocks, the *cock* which carries the pendulum is a strong piece of brass, or in large clocks a cast-iron frame, fixed firmly to the wall at the back of the clock. In order that the pendulum may hang so that the spring will have no tendency to twist it as it swings, the top of the spring is pinched or *clipped* between two thick pieces of brass or iron called *chops*, and firmly screwed there; and these chops have square ends exactly at right angles to a line down the middle of the spring. A little way below the top of the chops and exactly in the middle, a strong steel pin is put through them and the spring between them, at right angles to the plane of the spring, and this pin has shoulders so that its thin ends beyond the shoulders will just drop into two nicks or V's, in the sides of the cock, with the shoulders resting against the sides. It is evident that the effect of this will be, that the weight of the pendulum will cause the square ends of the chops, and therefore the top of the spring, to be horizontal; and so, if the pendulum is made symmetrically, as of course it ought to be, it will vibrate in a vertical plane at right angles to the line which is the top of the spring, without any tendency to twist. The two V's should be made as nearly level as possible, and the clock-frame must be so placed that the pallet arbor is exactly at right angles to the plane of motion of the pendulum. If it is not, the pendulum will slide backwards and forwards in the fork by which it is connected with the pallets. In common clocks, both house and turret clocks, the cock is fixed to the clock frame, and has merely a slit in it into which the spring fits, having a piece of brass riveted on to the top to keep it from dropping through the slit."

The length of a pendulum beating seconds is 39·1393 inches.[1] Now, supposing our clock to be furnished with such a pendulum the seconds hand would evidently be fixed on the axis *a*, of the scape-wheel, Fig. 1167. The scape-wheel has 30 teeth, and as two vibrations of the pendulum are required in order that one tooth may occupy the place of its predecessor, it follows that the seconds hand will make a complete revolution in 60 seconds, or one minute. The pinion H, fixed to the axis *b* of the wheel K, is prolonged to the left of the figure, where it engages

(1) A seconds pendulum in the latitude of London, would by the effect of its own gravity alone, if unassisted and unopposed, make 86,400 vibrations in an artificial solar day, or 86,163·09 in a natural sidereal day.

with a wheel *c*, fixed to a hollow cylinder which surrounds the axis of the seconds hand, and carries the minutes hand. By the side of the wheel *c*, and in the same hollow axis, is a second wheel *d*, which engages with a wheel *e:* the axis of *e* carries a pinion *f*, which engag es with the wheel *g;* this wheel *g* is fixed to a second hollow axis, which surrounds the preceding and carries the hour hand.

When the weight A has unwound the cord from the barrel B, the rotation of the barrel of course ceases until the weight has been again raised by winding the cord again on the barrel. This is done by turning the barrel in the contrary direction to its usual motion by means of a key, into which the square arbor *k* fits. To prevent the whole train of wheels and pinions partaking of this retrograde motion, a ratchet-wheel similiar to that noticed in Fig. 1162, is employed here also. This ratchet-wheel P, Fig. 1166, is fixed to the axis of the barrel B, and consequently turns with it in whatever direction it may move. A click Q, is kept pressing against the ratchet by means of a spring R. The click and the spring are attached to the great wheel C, so that when the barrel B rotates under the action of the weight A, the great wheel C must turn also by the pressure of the ratchet-wheel and the click; but when the barrel is turned in the contrary direction, as in winding up, the teeth of the ratchet-wheel pass rapidly in succession under the click, and the great wheel C does not rotate.

The advantages of a pendulum as a regulator are evidently confined to clocks permanently fixed in a position where the pendulum can swing and the escapement act undisturbed. In watches and chronometers intended to be carried about, such a regulator has been contrived as shall be uninjured by alteration in position, and at the same time present as far as possible the advantages of the pendulum. The balance described in Fig. 1162 satisfies the first condition, but not the second. Such a regulator, deriving all its motion from the coiled spring, yields to all the variations in this force, and is subject to other changes as already noticed. But the objections to such a balance are got rid of by the introduction of the *spiral spring*, (another of Hooke's admirable inventions,) which enables it to oscillate of itself independently of the main-spring. It is of the same form as the main spring, Fig. 1158, but is minute in size and delicate in structure. Its interior extremity is attached to the axis of the balance, and its outer extremity is pinned into a cock set on the frame of the watch. See Fig. 1175. The spiral naturally seeks the position of equilibrium; for whether the balance be turned in one direction or the other, the spiral coils are either distended or compressed, and tend by virtue of their elasticity to occupy the position of repose, or that given to them in the process of hardening and tempering, and thus restore the balance to its first position. But the moment the spiral has reassumed its position of equilibrium, the balance, moving by its acquired velocity, still continues to turn, causing the spiral to move also until the elasticity of its coils and the momentum of the moving wheel counterbalance each other, and the balance is for a moment brought to rest: the action of the spiral being thus at an end, re-action takes place, the coils move in a contrary direction swinging round the balance, the momentum of which strains to the utmost the spiral spring until it again stops, and swings the balance back. In this way the balance is made to oscillate from one side to the other, resembling to a certain extent the vibrations of a pendulum. In effect the spiral is to the balance what the moving weight is to the pendulum. It is also important to note that the times of oscillation of the balance are independent of their amplitude, provided the spiral be properly arranged.

This valuable property of the balance does not, however, qualify it to act as a regulator without further aid. The escapement must be formed in such a way as to remove the balance as much as possible from the action of the main-spring, which would cause the times of vibration of the balance to vary according as the main-spring acted with greater or less vigour. For a long time the recoil escapement, or one with pallets such as is shown in Fig. 1162, was used, and it is still used in common watches. In this case the part of the mechanism which serves to regulate the movement is arranged as shown in the Figure, only that the axis of the balance is furnished with a spiral spring. The regularity of the motion thus obtained is very great, but much was still wanting. The balance was increased in value by the addition of the spiral; the escapement also required modification. We will notice the principal forms of escapement; the effect of which has been to make watches perform their work with very great accuracy.

The first is the *cylindrical* or *horizontal escapement;* another invention of Graham's. The verge, instead of being provided with two pallets as in the recoil escapement, is of the form shown at B C, in Fig. 1168, and shown separately in Fig. 1169. The portion *a b* is a hollow half cylinder, which is further reduced by cutting out the portion *c*. The semi-cylindrical portion situated above *c* has an important office to perform. The scape-wheel is situated in a plane perpendicular

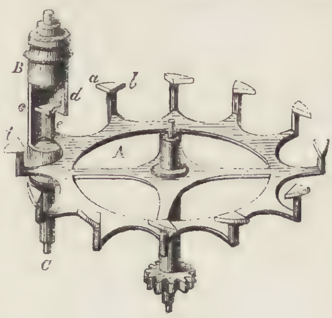


Fig. 1168.

Fig. 1169.

to the axis of the balance, and its teeth elevated above its surface engage with the hollow cylinder as shown in Fig. 1168. Figs. 1170 and 1171 further illustrate

the mode in which the cylinder arrests and allows to pass the teeth of the wheel. By means of the oscillations of the balance, the cylinder A rotates first in one direction and then in the other. A tooth C presents its point to the exterior surface of the cylinder, Fig. 1170, but immediately after this has

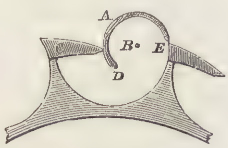


Fig. 1170.

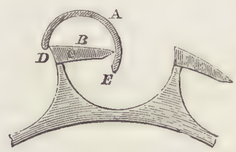


Fig. 1171.

taken place, the cylinder turns into the position Fig. 1171, and the tooth C, obeying the action of the motive force, is now brought into contact with the interior face of the cylinder; the cylinder then assuming its first position allows the tooth C to escape, and arrests the progress of the next tooth by presenting its exterior surface thereto, and so on.

In this escapement so long as one tooth is arrested by one of the two faces of the cylinder, the tooth does not tend in any way to make it move in one direction or the other, the cylinder oscillating under the action of the spiral only. Nevertheless, the friction which it undergoes in arresting the motion of the teeth, in addition to the other resistances which oppose the motion of the balance, tends to diminish the amplitude of its oscillations, and the watch would soon cease to go, if the main-spring did not from time to time restore to the balance the motion which these resistances tend to destroy. On this account the teeth are formed in such a manner that at the moment when the tooth C, Fig. 1170, having glided over the exterior face of the cylinder begins to escape, its convex form presses on the edge D, and thus accelerates the motion of the balance. For a similar reason the other edge, E, of the cylinder is bevelled so that when the extremity of the tooth attains this edge it glides over the small oblique face and gives an impulse to the balance.

The cylindrical escapement bears the same relation to the balance as the anchor escapement does to the pendulum. In these two escapements as soon as one tooth is stopped, either by the cylinder or by the anchor, it remains completely motionless or *dead.* In each escapement the regulator is constantly under the influence of the moving force, which although feebly exerted still exists, since the teeth rub upon the piece which arrests them, and at the moment when they are set in motion they give an impulse to this piece. In order to get rid of the continual influence of the main-spring upon the regulator, the *chronometer movement* or *detached escapement* has been devised. It is called *detached,* because the vibrations performed by the balance are nearly detached from the pressure of the motive power during the greater part of its arc of vibration. This escapement is shown in Fig. 1172, in which *e* is the scape-wheel, made either of brass or steel, with the teeth considerably undercut: *p* is the steel roller or main-pallet, fixed on the arbor of the balance: it has an opening in it, the face of which is much undercut, and a piece of hard stone, such as a ruby, is set in this opening for the points of the teeth to act upon: *l* is a stud, firmly fixed to one of the plates of the chronometer; and to this stud the detent spring *s* is secured by a screw:

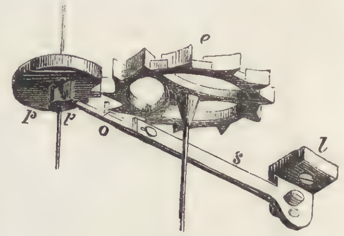


Fig. 1172.

this spring is made very slender in the part *o*, and it is only by the yielding of this thin part of the detent-spring that any motion can be given to the detent for the purpose of unlocking the wheel, so that some part of this spring may be considered as the centre of motion of the detent; at *o* is a ruby pin, inserted in the detent in such a way that the teeth of the wheel may in succession rest on the pin, in which state the wheel is said to be locked: by means of a screw the distance of the ruby pin from the centre of the wheel, and consequently the strength of the locking, can be adjusted: to the inner side of the detent is attached a very delicate spring, called the *lifting-spring,* which rests upon, and extends a little beyond, the end of the detent. Concentric with the main-pallet, and just above it, is a small lifting-pallet, *p.* The mode of action is as follows:—In the position given in the figure, the lifting-pallet is about to move round with its face in contact with the lifting-spring, which in the course of vibration it lifts, and with it the detent, so as to raise the pin *o* clear of one of the teeth of the scape-wheel. By the time the wheel is free from the ruby pin, the main-pallet has advanced so far as to be ready to receive an impulse from another tooth, and before the tooth escapes the lifting-pallet parts with the spring, and the detent resumes its place on the head of the screw, in which position the ruby pin receives the point of another tooth, as soon as the tooth has escaped from the ruby face of the main-pallet. The balance having performed this vibration by the impulse given to the main-pallet, returns by the force of the balance-spring, and with it the lifting-pallet, the rounded side of which, pressing against the lifting-spring, raises it from the detent, and passes without disturbing the detent, which, is not again lifted till the balance has completed the present vibration, and returning for the next again brings the face of the lifting pallet in contact with the lifting-spring, which, with the detent, it raises, and the act of escaping again takes place, the balance making 2 vibrations for every impulse, as in the duplex, which is next to be described. Thus it will be seen, that at the moment when one tooth escapes, another tooth of the same scape-wheel gives an impulse to the edge of the indentation made in the main pallet, attached to the axis of the balance: and in this way the moving power by an almost instantaneous motion

restores to the balance the motion which it may have lost during two oscillations. With this exception it oscillates independently of the main-spring. Another great advantage of this escapement is, that it requires no oil.

The *duplex* watch is so named from its escapement-wheel having two sets of teeth on its rim; the cogs t' being placed upright nearer the centre, while the long teeth t are in the plane of the wheel: hence arises a *double* action. b is the balance. A watch of this kind will continue for a long time without cleaning, or requiring a fresh application of oil. It is, however, of delicate construction, and if not well made and put together, it is liable to stop in the pocket, and is expensive to repair if injured.

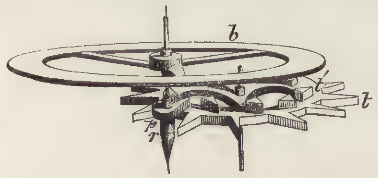


Fig. 1173.

The *lever* watch is one of the best forms for ordinary use. It is so named from there being a lever added to the action of the escape-wheel to give impulse to the balance. In Fig. 1174, e is the escape wheel, which gives motion to the ruby pallets p: l is the lever which gives impulse to the balance b. This form is strong, not liable to get out of order, and is easily repaired.

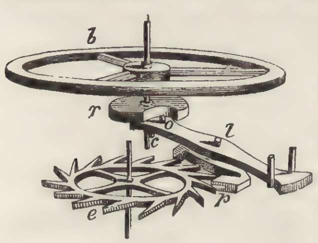


Fig. 1174.

In pendulum clocks the rate of going depends upon the effective length of the pendulum: by screwing up the bob the clock goes faster; by letting it down it goes slower. The regulator of a watch requires adjustment in a somewhat similar manner. The duration of the oscillations of a pendulum depends upon the intensity of the earth's attraction and upon the form of the pendulum itself. As the earth's attraction is, at the same spot, a constant quantity beyond our control to alter, any variations in the oscillations of the pendulum must be made by altering its form. So also the duration of the oscillations of a balance depends upon its form and upon the force of the spiral which sets it in motion; but, contrary to what happens in the case of the pendulum, it is in modifying the force of the spiral, and not in changing the form of the balance, that the duration is varied. Thus by altering the fixed point of the spiral spring, the acting part is made longer or shorter. Thus in Fig. 1175, A B D is the spiral spring, or a portion thereof. Its outer end is pinned into a cock set on the frame at A. The pointer C B E turns on an annular or hollow pivot at C, the hole being left in its centre for the arbor of the balance, or the *verge* to go through. At B there are two small pins close together, between which the spring is passed, and which therefore determine the point from which it begins to bend; so that as the pointer or regulator, C B E, is moved towards the right, it makes the spring vibrate faster, and to the left, slower. When the regulator has been moved to the right as far as it will go, and the watch is still found to go too slow, the spring must be taken out and shortened by putting the outer end further through A, and drawing the inner end further out through the other cock by which it is pinned to the balance.

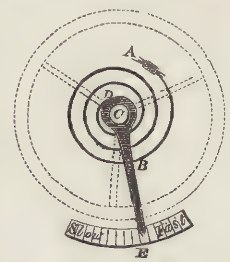


Fig. 1175.

Variations in temperature greatly influence the rate of going of a clock or watch, by causing the pendulum or the balance to contract or expand. The effect of a difference of temperature of 25°, or that which usually occurs between winter and summer, would occasion a clock furnished with a pendulum having an iron rod, to gain or lose six seconds in twenty-four hours. Different methods of *compensation* have been contrived to correct this source of error, or, in other words, to construct such a pendulum, that its centre of oscillation shall, under every change of temperature, remain at the same distance from the point of suspension. In the mercurial pendulum already noticed, the bob or weight consists of a jar of mercury so adjusted, that in proportion as the pendulum rod becomes longer, the mercury ascends in the jar, and *vice versâ*, by which means the centre of oscillation is always kept at the same distance from the point of suspension. In the gridiron pendulum parallel brass and steel rods are used, and the compensation is produced by the greater expansion of the brass rods, which raise the bob upwards towards the point of suspension as much as the steel rods elongate it downwards.[1]

In the chronometer the compensation is effected by means of an *expansive balance*, two forms of which, one with weights, and the other with screws, are shown in Figs. 1176, 1177. The making and finishing of a balance of this kind is one of the most difficult tasks which the mechanic has to perform. It is thus described: A circular piece of steel, of the thickness of the intended balance, is turned perfectly true, with a small hole in the centre, in which its arbor or axis is afterwards secured, and upon which it is ultimately poised. The piece of steel is then put into a melting-pot, and sometimes secured to it by a pin through a hole in the centre, with a quantity of fine brass, sufficient, when melted, to cover the steel. After a gradual cooling, the superfluous brass is filed away from each side of the flat piece of steel, so that the steel is completely cleared of brass everywhere except

(1) In Captain Kater's Chapter on the Pendulum, appended to the Treatise on Mechanics in "Lardner's Cyclopædia," such instructions are given as will enable an artist or an amateur to make a compensation pendulum.

on the edge. If the juncture of the ring of brass to the steel which it now encircles be perfect, the brass is filed upon its outer edge so as to form a ring of tolerably equal thickness all round, but double the thickness required. It is next carefully and equally condensed with the hammer or burnisher; the steel is then turned out of the centre, and the brass from the outer edge, leaving a compound ring perfectly true, of the proper thickness for the balance, the brass portion being about twice the thickness of the steel. Within the steel rim, a bottom is left, out of which the bar A B is cut. When the balance is ready for adjustment, the compound rim is cut through on opposite sides, *a a*, so that each arm may present nearly a semicircle, secured at one end of the bar A B, and free to move through the rest of its length. The weights W W, Fig. 1176, are turned out of a piece of brass, with a groove equal in depth to the thickness of the balance, and of sufficient breadth to

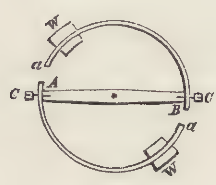


Fig. 1176.

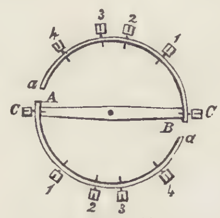


Fig. 1177.

allow the brass to move round on the balance with a slight pressure. Each weight is secured in its place by a small screw passing through the outer edge, and pressing against the rim of the balance. Two screws, C C, called *mean-time screws*, are used for altering the rate of the time-keeper, and have nothing to do with the compensation.

This spring acts in the following manner: an increase of temperature diminishes the elastic force of the balance spring, which would cause the machine to lose; but the same degree of heat expands the outer brass ring on the rim of the balance more than it does the inner or steel one, and these not being able to separate, a curvature of the whole arm takes place, which carries the weight W towards the centre, whereby the inertia of the balance is so much lessened as to allow the balance-spring to exert the same influence over the balance as it had previous to the change of temperature. A diminution of temperature increases the elasticity of the spring, which would cause the machine to gain, but the brass contracting more than the steel, curves the arm outwards, thereby increasing the inertia of the balance, and allowing the spring no more influence over it than it had previous to the change of temperature. The proper situations of the weights W W are found by experiments on the rate of the machine. The nearer the weights are to the movable ends *a a* of the arms, the greater the space through which they move by any change of temperature, and the greater the variation in the inertia of the balance; so that if an increase of temperature cause the machine to lose, or a decrease to gain, it shows that the compensation is not sufficiently active; *i.e.* the inertia of the balance is not altered sufficiently to compensate for the effect produced by the increased or diminished elasticity of the spring, and consequently the weights must be set nearer to the moveable ends *a a* of the arms. If an increased temperature cause the machine to gain, or a decrease to lose, the weights must be moved further from the moveable ends *a a* of the arms. In adjusting these balances made with screws, it will be seen that the moving in or out of the screws 4 4, will produce a greater effect than 3 3, and these than 2 2, and so on; and that in the adjustment two opposite screws must always be moved in or out the same quantity. The mean-time screws C C produce no effect on the compensation, as no motion is given to them by the curvature of the arms. In every balance-spring of sufficient length, there is a part which is isochronal, or nearly so, and this length being found, it is not desirable to alter it in bringing the machine to time; for if shortened, the long vibrations will be quicker than the short ones, and if lengthened, the short vibrations will be quicker than the long ones. To avoid this source of error, the two screws C C have been introduced, the drawing out of which from the centre causes the machine to lose, and the screwing them in to gain.

Some years ago, Mr. Dent introduced a balance-spring of glass Fig. 1178 shows one of his compensation balances, with the spiral spring attached.

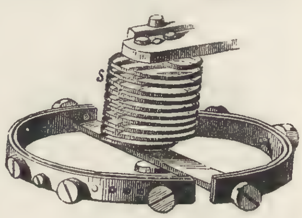


Fig. 1178.

The reader will now understand the essential differences between a clock and a watch. A clock or a watch has been defined as a machine consisting of a train of wheels turned by a weight, a spring, or any other nearly constant force, and of which the velocity is regulated by attaching to it a pendulum, balance, or fly-wheel, which always vibrates or revolves nearly in the same time. And the only distinction (except the arbitrary one of mere size) between a clock and a watch is, that a watch will go in any position, but a clock only in one. A chronometer is a very accurate kind of watch. What is called a *pocket chronometer* resembles a common watch, and is made to go the same time with once winding up, namely, 30 hours. Those used for determining the longitude at sea are larger, having dial-plates 3 to 4 inches in diameter, and are usually made to go from 2 to 8 days with one winding up. In addition to the hour, minute and seconds circles, there is one which denotes the time in days that has elapsed since the last winding up. Each chronometer is well secured in a brass box, mounted on gimbals, in order that one uniform position may be preserved, and the whole is enclosed in a mahogany case.

Where there is vertical space at command, a weight is used as the motive power, and a pendulum as the regulator. If the clock is to occupy only a small space,

as in chimney dials, a weight would be very inconvenient on account of the frequency with which it must be wound up. In such case a spring is substituted for the weight, but no fusee is used, since the regulator is a pendulum, the oscillations of which are not greatly influenced by the variations in the force of the spring. A main-spring and a balance, furnished with a spiral, are always used in watches, which differ from each other only in the form of escapement. In old watches the pallet or recoil escapement was used, as shown in Fig. 1162. Such an escapement required the intervention of a fusee to render uniform the action of the main-spring, notwithstanding its variations in force. In modern watches the use of the cylindrical escapement allows the fusee to be dispensed with, and a much thinner and flatter watch is the result. In chronometers the detached escapement is used, and the fusee retained.

When a clock is wound up, the hands do not make a retrograde motion, for the reason already explained, but remain stationary, and begin to move again when the winding is completed. In the exact observations of astronomy it is of importance to prevent the error likely to arise from the stopping of the clock during the operation of winding up. By the following contrivance by Huyghens, the clock can be wound up without stopping it:—The pulley A, Fig. 1179, furnished with a notched groove, is fixed upon the arbor of the first wheel. H is a similar pulley, pinned on the side of the ratchet R, and movable on a stud fixed in the frame. An endless cord is put over these two pulleys, and under the pulleys B and C, which carry the weights W *w*. It is evident that half of the large weight W is sustained by the pulley H, and the other half by the pulley A; and that half the weight will continue to bear upon A although the pulley H be turned so as to raise the weight W. This is what happens at the time of winding; for, by pulling the cord next B, the pulley H revolves, and raises or winds p the weight W, which still continues to act with half its weight on A, and consequently keeps the clock going. The ratchet R only turns during the winding, and is prevented by a click from going back. It is said, however, that this ingenious method does not answer very well in practice, unless a chain be used instead of a cord: for the pulleys A and H wear the cord so fast as to make a good deal of dust, which soon renders the clock foul. The chain is also objectionable on account of its weight, which sometimes aids and at other times counteracts the moving power.

Fig. 1179.

When the maintaining-power of a clock or of a watch is a spring acting directly upon the train without the intervention of a fusee, as in Fig. 1162, the watch stops during the winding up, as already explained: but by a simple arrangement the maintaining-power can be kept up during the winding. For this purpose the main-spring is placed in a barrel attached to the great wheel, and it is wound up by turning round the axis to which its inner extremity is attached. It is evident that if this interior axis be left undisturbed, or it be made to turn so as to coil the spring round it, the outer extremity of the spring will constantly act upon the circumference of the barrel, and will cause the spur-wheel attached to it to continue its motion. It is in this way that the main-spring of chimney clocks is arranged, and also in flat watches, where the cylinder escapement allows the fusee to be dispensed with. Of course, the axis to which the spring is attached in the interior must be provided with a ratchet-wheel, which allows the winding to take place in one direction only.

When the main-spring acts through the medium of a fusee, the winding up is performed by turning the fusee in a direction contrary to that in which it is accustomed to turn under the action of the main-spring. In this way the chain, which by the action of the spring had been dragged from the fusee and wound upon the barrel, is again wound upon the fusee: at the same time the barrel turns under the tension of the chain, and exerting a pulling force upon the exterior end of the main-spring, increases the number of the coils round its axis, and presses them closer together. In order that the retrograde movement thus given to the fusee during the winding up may not be transmitted to the whole train, a ratchet-wheel is provided, through the medium of which the fusee acts upon the train. This ratchet-wheel is let into a cavity of the great wheel, which is furnished with a catch, by which the motion of the fusee is transmitted.

To prevent the stopping during the winding up, Harrison's *going barrel* or *ratchet* is used in weight clocks, and the *going fusee* in watches and spring-clocks. Fig. 1180 shows the barrel with its ratchet and click; but in this case the click, *c*, is not placed on the great wheel, but upon another wheel riding on the arbor of the barrel, between the great wheel and the barrel ratchet: this wheel has also ratchet teeth cut upon it, but turned the opposite way to the barrel ratchet, as shown at R; and the click, R C, belonging to it, is a long arm turning on a pivot C in the clock-frame; and this second ratchet-wheel is connected with the great wheel by a spring, S S, one end of which is fixed on the ratchet-wheel, and the other end presses against a pin on the great wheel. The action is as follows: while the clock is going, the weight pulls the barrel and both ratchets to the left, and the going-ratchet, by means of the spring, S S, presses the great wheel in the same direction: and as the clock goes on,

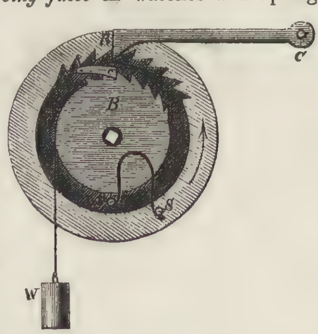


Fig. 1180.

one tooth after another of the ratchet R slips under the long click, and this causes the drop, which may be heard about every 5 minutes in regulators and good watches. When the weight is taken off the barrel by winding up, the going-ratchet immediately flies back a little towards the right, but is stopped as soon as one of the teeth arrives at the click, and there it is held: the spring continues to press the great wheel as before, with nearly as much force as when the weight is acting, and so keeps the wheel in motion for the short time that the clock is winding up.

That part of the clock which publishes the hours to the ear is nearly as complex as that which indicates the course of time to the eye. If, however, the clock is required to strike only one at every hour, all that is necessary is to put a pin into either of the wheels of the dial work that turns in an hour, and a hammer-tail or lever over it, so that the pin will begin to raise the hammer about a quarter before the hour, and just slip from under it when the minute-hand points to the hour. Instead of the pin, a flat piece of metal, cut into a spiral form, and called a *snail*, may be put upon the front of the wheel. The effect of this is to distribute the work of raising the lever over the whole hour with much less friction than in the former case. Now, it will be evident, that as the wheel H, Fig. 1181, bearing the minute-hand M H, goes round in the direction of the arrow once an hour, it will carry round with it, in the same time, but in a contrary direction, a similar wheel H′ with the same number of teeth engaging into it. Now the snail *s* being attached to this second wheel, and the hammer-tail H T resting on the snail, as shown in the figure, a

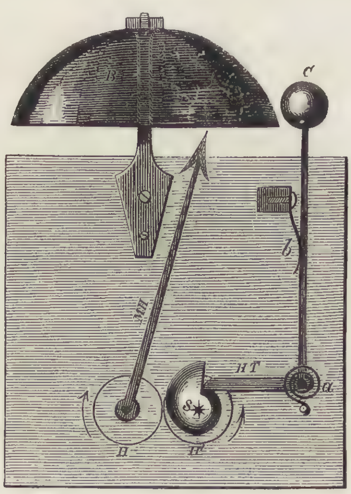


Fig. 1181. ONE STROKE EVERY HOUR.

few minutes after a stroke has been made, the snail, by gradually raising the hammer-tail, will remove the knob C of the hammer from the bell B until another hour is just on the point of completion, when the knob is at its greatest distance from the bell. During this time the spiral spring *a* is being more and more strained, so that when the snail suddenly releases the hammer-tail, the spiral spring causes the knob to strike suddenly against the bell, and the spring *b* forces it away again, and the point of the hammer-tail, falling into a position nearest to the centre of motion of the snail, as shown in the figure, the process goes on as before.

The arrangements for striking the hours and quarters is complex, and is often referred to technically as the *clock-work*, or the *clock-part*, the going part which moves the hands being called the *watch-work* or the *watch-part* even in a clock. Fig. 1182 shows the striking part of a clock in which the maintaining-power is a weight. The striking part is also moved by a weight attached to the cord R, which is coiled on the cylinder B, and the motion thus imparted to B is transmitted to the spur-wheel C attached to the same arbor. The wheel C engages the pinion D, and thus gives motion to a second wheel, E, which, acting on the pinion F, turns a third wheel, G: this transmits its motion to the pinion H, and consequently to a fourth wheel, I: I engages with the pinion K, and thus moves a fifth wheel, L: lastly, L turns the pinion M, the axis of which carries a fly, ff', which regulates the movement. While this train of wheels is in

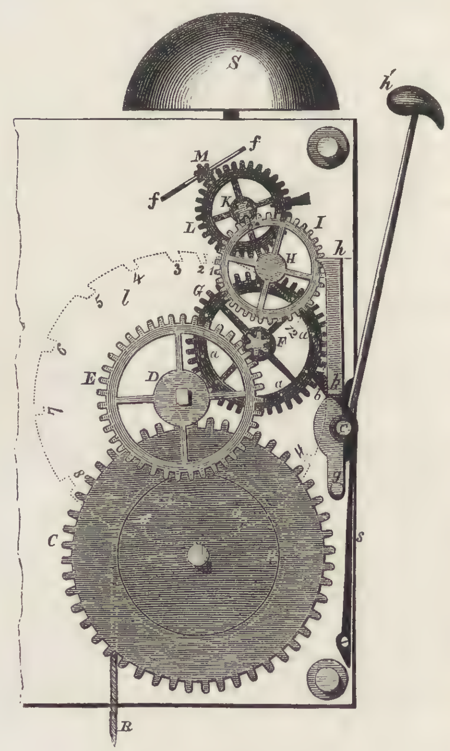


Fig. 1182. THE STRIKING PART.

motion under the action of the maintaining weight, certain pins, *a a*, projecting from one of the sides of the wheel G, successively raise the lever *b*, which lever causes the rotation of the axis *c*, to which the tail of the hammer is attached. As soon as one of the pins *a a* escapes from under the lever *b* after having raised it, this lever is forced by the action of a spring into

its first position, and the hammer *h* is thus brought towards the bell. If the tail of the hammer were rigid, the hammer would not strike the bell, but being flexible and elastic, the hammer, by its acquired velocity, passes beyond its position of equilibrium and strikes upon the bell, when it is immediately driven away again by the elasticity of its tail. Thus it is evident that the hammer must strike a blow upon the bell every time that one of the pins *a a* raises the lever *b*.

When the clock is not striking, a pin *o*, in the side of the wheel I, bears upon the extremity *h* of a lever *g h*, and the train of wheels is thus prevented from moving. This lever, moving on a point *g*, is moved aside by a pin fixed in the wheel on the arbor of the minute hand, (corresponding to E, Fig. 1162,) so that on the completion of each hour, when the clock is to strike, the pin *o* is thus released, and the train allowed to act. If the lever *g h* falls back into its first position, the wheel I is stopped after having made a single revolution: one only of the pins *a* acts upon the lever *b*, and the hammer strikes only once on the bell. In order that the hammer may strike the hour as indicated by the hands on the dial, a knife-edge, *k*, attached to the lever *g h*, presses upon the edge of what is called a *count-wheel*, shown by the dotted line *l*. Certain notches or indentations are made at unequal distances in the edge of *l*, which is called the *locking*-plate, and as it is attached to the axis of the great wheel E, it revolves in the same time with the striking movement, but with great slowness, and presents, in succession, the different parts of its edge to the knife-edge *k*. If, at the moment when the lever *g h* falls again, the knife-edge *k* enters into a notch, the extremity *h* of the lever stops the pin *i;* but if the knife-edge *k* is opposed to a portion of the wheel *l* situated between the notches, the lever *g h* cannot stop the pin *i*, and the striking apparatus continues to move until the wheel *l*, in turning, brings round a notch for the edge *k* to fall into.

The wheel *l*, which moves through only a small space each time the clock strikes, performs an entire revolution in 12 hours, at the end of which time the hours of the same name recur. During this time the wheel I revolves as many times as the hammer strikes the bell; *i.e.* 78 times if the clock strikes only the hours, and 90 times if the hammer strike once for each half-hour, as is common in French chimney-clocks.

The principle upon which the count-wheel is constructed does not allow of the hands being set back, and being liable to derangement, and troublesome to adjust, it has been superseded in English clocks by the *rack and snail*, (invented by Tompion, the father of English clock-making,)[1] which allow the hands to be set backwards or forwards as required. The count-wheel is still used in the best French clocks and in cheap wooden clocks.

Fig. 1183[2] will enable us to explain the *striking* and *repeating* work of an eight-days clock. In a companion figure, which we have not copied, are shown certain wheels, P Q R, with their respective pinions, which constitute the movement of the striking part, and the fan S regulates the velocity with which they move. The wheel P has 8 pins, which lift the cross-piece *t* of the arbor T 8 times in each revolution of the wheel P: these elevations of the piece *t* occasion so many revolutions of the arbor T, which arbor has its pivot projecting to V behind the frame, and carrying on its squared projection the hammer V. The hammer is consequently raised every time a pin of wheel P moves the piece *t;* W is a long and strong spring, called the *hammer-tail-spring*, attached to the back plate of the frame, and pressing with its upper extremity under the cross pin, passing through a hole in the arbor T, near the face of the back plate; so that when the hammer is raised at any time, the spring W urges it back again with a *smart blow*, and makes it strike the bell behind the frame; but to prevent the blow being too strong, a counter spring, U, is fixed to the contiguous pillar, which breaks the violence of the blow, and makes the hammer return smartly to its place when the blow is made; this spring U also serves as a guard, in case a stroke of the hammer should be made when the bell is taken off.

In the centre of the figure is the arbor of the centre wheel, the end of which is seen within, at the projecting end of the squared part of the tube, or cannon, and is called the *cannon-pinion:* the tube of this portion is put tight on the arbor of the hour or centre-wheel, and has a spring placed on the hour-wheel arbor, pressing its posterior surface so as to force it forwards against the cross-pin that keeps the hands on: this action of the spring occasions so much friction, that although the tube is carried round by the hour-arbor, yet it is capable of being moved round by its hand placed on the square end independently of this arbor, for the purpose of setting the hand to the requisite minute on the dial. The cannon-pinion has 40 teeth, and impels a similar pinion, *g*, round also in an hour: this pinion *g*, called the *pinion of report*, has a pinion of 6 on its arbor, and is pivoted into the cock *h*, so that the small pinion of 6 also revolves in an hour. This pinion of 6 again impels the wheel *i* of 72 teeth in $\frac{72}{6}$ of an hour; *i.e.* in 12 hours: this 12-hour wheel has also a

(1) Mr. Adam Thomson, in his amusing and instructive little work on "Time and Time-keepers," (1842,) states that Tompion and Graham were buried in the same grave in the nave of Westminster Abbey. A slab bore the following inscription:—"Here lies ye body of Thomas Tompion, who died November 20th, 1713, aged 75. Also Geo. Graham, Watchmaker and F. R. S. whose curious inventions do honour to ye British genius, whose accurate performances are ye standard of Mechanic skill. He died ye 16th of November 1751, in ye 78th year of his age." Mr. Thomson feelingly remarks, "Watchmakers, the writer among the number, until prevented by recent restrictions, were in the habit of making frequent pilgrimages to the sacred spot: from the inscription and the place they felt proud of their occupation, and many a secret wish to excel has arisen while silently contemplating the resting-place of the two men whose memory they so much revered." The slab was removed in 1838, and a small lozenge of marble with the name "Tompion 1713," and "Graham 1751" substituted in its place.

(2) This figure is reduced, and the description abridged from one of the admirable articles on Clock and Watch-work, in Rees's Cyclopædia.

tube surrounding the tube of the cannon-pinion, but in such a way that a third tube, attached to the bridge K, is interposed between the two tubes of the cannon-pinion and 12-hour wheel: the use of this third fixed tube is to prevent the friction of two tubes revolving in contact with such different velocities as 12 : 1. On the exterior tube of the 12-hour wheel the hour-hand is inserted; and it is evident that whenever the minute-hand carries the cannon-pinion round, the pinion of report *g* also moves the same quantity, and by means of the small pinion of 6 the wheel *i* must, at the same time, move $\frac{1}{12}$ of the same space, and consequently the 2 hands are so connected that one cannot move without the other, supposing them to be both fast to their respective tubes; but the hour-hand is put on the round part of its tube, and kept to it by mere friction, and therefore may be put to any hour without carrying the minute-hand round many revolutions, and yet, when once placed right, it preserves its relative velocity as though it were more firmly attached to its tube. I is the arbor of the seconds-hand, which revolves in a minute, and which measures the 120th part in its divided small circle on the face of the clock at so many vibrations of the pendulum, or at so many half-rounds. To the 12-hour wheel *i* is pinioned fast an indented spiral piece of metal, called the *snail*, which also revolves in 12 hours. Each indentation of the snail subtends an angle of 30° ($\frac{360°}{12}$), so that one indentation, whether near to the centre of motion or far from it, is exactly the measure of an hour's motion of the 12-hour wheel The steel piece *m n* is called a rack from the teeth on the cross piece *m*, the lower cross piece of which is called the *rack-tail:* this rack is movable on a pin or stud at the lower angular point, near which the horse-shoe spring *o*, called the *rack-tail spring,* presses to keep a pin on the remote end of this tail, against that indentation of the snail which happens to be contiguous to it. On the lever, between *m* and *n*, is a bend to prevent its touching the winding arbor F of the fusee belonging to the striking part: also at *m* is a strong steel pin projecting from the rack. Above the rack is a horizontal steel bar, *p q r*, movable on a stud at *r*, which is called the *hawk's-bill,* from the bill or angular piece at *q* that catches the teeth of the rack. The piece *s*, fixed to the protruding pivot of the wheel (next the pin wheel) near its lower extremity, and revolving with it, gathers up a tooth of the rack at each revolution, on which account it is called the *gathering-pallet;* the catch of the hawk's-bill having a contrary slope, gives way in the mean time, and comes back again by its own gravity. The pinion on this pivot driven by the pin-wheel (which has 64 teeth and 8 pins) has 8 leaves, and therefore revolves once every time that the hammer of the bell is lifted; but its gathering-pallet takes up a tooth of the rack at each revolution of its arbor, consequently a tooth of the rack is gathered up at every stroke of the hammer when the striking part is in motion. The angular piece, *t u v*, movable round an arbor, is called the *warning-piece;* its lower end, *v*, falls in the way of a pin in the small hour-wheel *g*, and its bent end *t* passes through an aperture, *w*, in the front plate of the frame, in such a position as to come in contact with a pin on the fly, which is therefore unable to revolve until this bent piece is lifted away from the pin. The bent end *t* also lies under the piece *s*, so that when it is lifted away from the pin on the fly it raises this piece and the hawk's-bill *q*. The action of the different parts may be thus explained: Whenever the hawk's-bill *q* is lifted from the teeth of the rack the spring *o*, pressing against a pin near its tail, makes it fall back till it meets with some obstacle to arrest its motion, which obstacle would be the pin of the pin-wheel in the front plate, if there were no other interposed before it had fallen so far back, but if the snail is in any other position than that wherein its nearest indentation towards the centre is contiguous to the pin of the rack-tail, the tail pin of the rack will fall upon the edge of the snail before the rack has fallen back to the pin *x*, and all the teeth of the rack will not, in this case, pass the catch of the hawk's-bill, but just so many as there are indentations or steps counted from the remote angular point of the snail to the step on which the tail-pin rests. In the position shown in the figure the tail-pin is resting on the 6th step of the snail, which denotes that 6 strokes will be given by

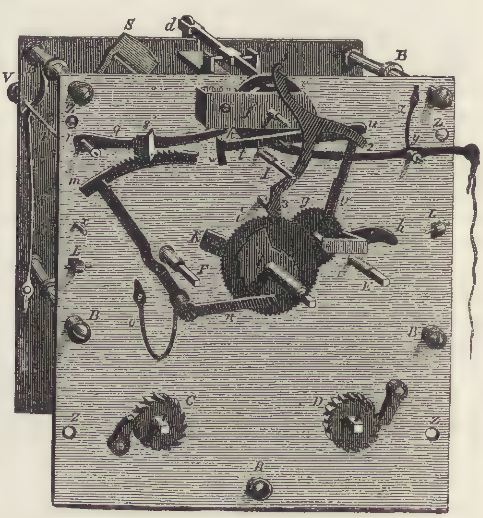


Fig. 1183. THE STRIKING AND REPEATING PARTS.

the hammer, or that 6 teeth of the rack are to be gathered up by as many movements to and fro of the piece *s:* but we see that only 5 teeth remain to be gathered up of the rack; hence we know that the clock has struck 1 out of 6, and is in the act of striking: the clock will therefore now continue to strike till the upper end of the gathering-pallet *s* falls on the projecting pin *m* of the rack, which will be as soon as the last tooth of the rack is drawn up to the hawk's-bill, in which situation the wheel Q cannot revolve any further till another hour has elapsed. After another hour is past, the pin of the wheel *g* will again elevate the warning-piece *v*, the bent end *t* of which will first be raised out of the way of the pin of

the pin-wheel, and the fly s will run on a revolution or two with a whistling noise, *i. e.* the clock will *give warning:* but the end p of the hawk's-bill has not yet been raised far enough by the pressure of the end t of the warning-piece to make the catch q clear the teeth of the rack; therefore the rack cannot yet fall back: presently, however, the hawk's-bill is lifted high enough by the continued motion of this pin: the rack falls back till its tail-pin rests on step 7 nearer the centre, which has now arrived at the point of contact, and therefore 7 teeth of the rack pass the catch q in the fall of the rack, and the hour of 7 is now struck before the tail of the gathering-pallet s falls again on the pin m of the rack, and stops the striking; at the same time the bend of the warning-piece catches the pin of the fly and stops it; and in this way any number of hours will be struck by the hammer on the bell that the snail regulates, which revolves once in 12 hours; and if any other cause than the pin of the hour-wheel g should lift the warning-piece within the hour, counting from warning to warning, the same number of strokes will be repeated, though it should be a hundred times or more. To convert this striking mechanism into a repeating mechanism, it is only necessary to place a lever y to revolve round a stud on the front plate of the frame at the point 7, with a slender spring z over it, to bring it back to its original situation, when the end placed under the warning-piece is elevated by depressing the exterior end, which may be done by pulling down a string attached to this end, as shown in the figure; and as often as the string is pulled, so often will the clock repeat the strokes of the current hour. The three-armed piece 1, 2, 3, called *strike or silent,* is differently made in different clocks. In our figure it is movable on a socket riveted to the end 3 of one of its arms, round a stud in the front plate of the frame, and as the socket has scarcely any shake, the other two ends, 1 and 2, move always in the same plane: at the end marked 1 is a pin projecting above the upper circumference of the face or dial of the clock, so that it may be moved to the right or left at pleasure: the end marked 2 has a slope like a wedge on that side which is next to the plane of the frame-plate, and the end of the arbor of the warning-piece projects so far as to touch the inclined plane: this arbor of the warning-piece has some shake in the direction of its length within the frame, and its posterior pivot passes between the prongs of a forked spring, which, resting against the shoulder of the pivot, pushes it close to the interior side of the front plate of the frame, where a similar shoulder stops it: when the pin at 7 is pushed to the right, the wedge of the end 2 pushes the arbor back, and the end v of the warning-piece being carried with its arbor nearer to the frame than it otherwise would be, falls in the way of the pin of the hour-wheel g, and the clock consequently strikes the hour regulated by the snail; but when the pin at 1 of the strike or silent is pushed to the left, the end 2 is withdrawn from the pivot of the arbor on which the warning-piece is fast, the spring in the frame pushes it forward so far that the end v of this warning-piece is clear of the pin of the hour-wheel g, which wheel, therefore, continues to revolve from hour to hour in a state completely detached from the mechanism of the striking part. In clocks which have no seconds-hand, there is a hand movable in a small circle in the dial, which answers the same purpose as the pin at 7.

The machinery for striking *quarters* is similar to that for striking the hours, only there are two hammers instead of one, and an additional set of pins on the striking-wheel for raising them. For what are called *ding-dong* quarters 2 bells are used, and the striking-wheel has 2 sets of pins on its opposite sides, which raise the 2 hammers alternately. If there are 4 or more bells, the rim of the striking-wheel is spread out so as to form a *chime-barrel* with pins sticking out from it like the barrel of a musical-box, and the hammers, which are all set on one axis, are raised by these pins.

Alarums. If the pendulum be taken off a clock with a recoil escapement, it will beat about as quickly as the bell is struck in an alarum; and the striking in an alarum takes place in the same way as if a double hammer were put on the end of the crutch of a recoil escapement long enough to reach the inside of the bell. In order to let off the alarum, the letting off pin is made movable on the wheel which carries it. "If the common letting-off pin were made movable upon the hour-wheel, we might make the clock strike when the long-hand is at 50 m. instead of 60 m.; and in like manner, if we put a letting-off pin for the alarum on a cap or *key,* which fits tightly on to the socket of the 12-hour wheel, we can make it let off with as much accuracy as is required at any portion of the twelve hours we please. The key which carries the pin, has its socket prolonged forward so as to carry a small dial or hour-circle under the hour-hand, which always travels round with it; but the key does not fit so tightly that it cannot be moved by the hand so as to make a pointer in the hour-hand point to any time we like on the alarum dial; and then it will let off at the time so indicated. There is no occasion for any stopping apparatus beyond a single lifting piece and a pin in the striking barrel, which rests against the stop on the lifting piece when it is not raised high enough to let the alarum go. The string of the weight is attached to a wheel exactly like a recoil scape-wheel, either of the crown-wheel or the plain kind, and when it is let off it runs till it is down. Of course it must not be wound up until within 12 hours of the time when it is intended to strike."

The Watchman's Clock, or *Tell-tale Clock.* In this clock there are a number of pins sticking out round the dial, one for every quarter of an hour, and it is the duty of the watchman on the premises, where such a clock is kept, to go to the clock every quarter of an hour, and push in the proper pin, thereby proving to the inspector, next morning, that he was vigilant during the night. Each pin admits of being pushed in during a few minutes only, and if the time be neglected it will be found sticking out, and will show the exact time when the watchman was negligent. In

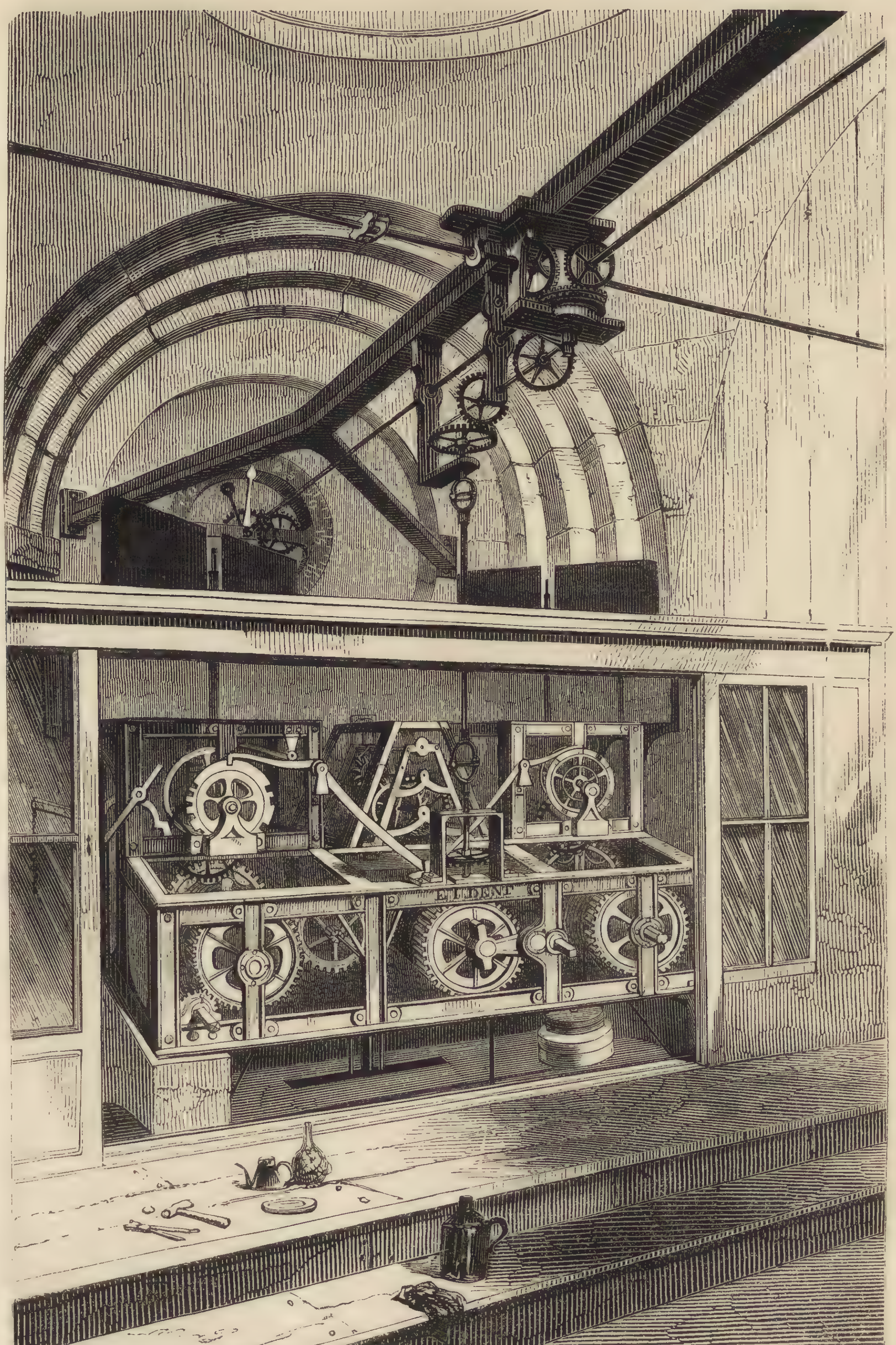
a tell-tale clock in one of the lobbies of the House of Commons the face and pins are enclosed behind a glass, and outside the clock-case is a handle communicating with a small lever standing over a part of the circle in which the pins move; and as the pins are carried round in a sort of movable dial, the effect of pulling the handle is to push the pin, which comes under the lever every quarter of an hour. In these clocks the pins are made to pass over an inclined plane some hours after they have been pushed in, and in this way are pushed out again.

In Mr. Denison's "Rudimentary Treatise" will be found an interesting chapter on Church clocks, together with an account of the negociations for the Great Clock for the New Palace at Westminster. One of the most remarkable clocks in London is that at the Royal Exchange, the working parts of which are represented in the full-page engraving which is to accompany this article. When Mr. Dent was engaged by the Gresham Committee to construct for the new Royal Exchange as perfect a clock as the state of the art allowed, he took the advice of, and submitted the results of his labours, to Professor Airy, the Astronomer-Royal. In the construction of this clock the trains are contained within a simple but strong cast-iron framing, in which every strain is so completely self-contained, that the operation of fixing the clock is easy, nothing more than a firm and level base being required for the framing. Hollow iron drums are used instead of wooden cylinders for the driving barrels, and wire instead of hempen ropes are employed for suspending the weights. The first of these improvements ensures a more permanent accuracy of form, and the use of wire-rope allows a smaller cord to be used, thus preventing the necessity for overlaying. In this way the weight exerts the same force to turn the barrel, which is not the case with a thicker rope covering the barrel in 2 or 3 layers. In this clock the hands are driven, and the hammers of the striking part raised, directly from the axis of the driving-barrel, without the intervention of wheels and pinions. Our engraving will show the rods and bevil-gear by which this clock indicates the hour on the *four* dials of the four external faces of the turret. The pendulum of this clock is compensated, and the first stroke of the hour is true to a second. For this purpose the lever and hammer are removed to their greatest distance before the time of striking, and the end of the lever remains delicately poised upon the rounded point of the projecting tooth of the pin-wheel until the exact time for striking has arrived, when it is released on the instant. The pendulum is thus described:[1]—"The centre rod of the pendulum is of steel, and is sufficiently long to pass completely through the bob or weight, which, however, is not immediately attached to it. Upon the bottom of this rod is fixed a nut, by turning which the length of the pendulum may be nicely adjusted, and upon which stands a hollow column of zinc, through which the steel rod passes freely. On the top of the zinc column is a metal cap, from projecting portions of which descend 2 slender steel rods, to the lower ends of which the weight, which is a hollow cylinder of iron, capable of sliding freely upon the zinc column, is suspended. Thus, while both the central steel rod, and the two smaller steel rods by which the weight is suspended, expand downwards upon any increase of heat, the position of the weight in reference to the point of suspension of the pendulum remains nearly the same, because the zinc column, though shorter than the central steel rod, expands to an equal extent upwards, and consequently raises the weight just as much as it is depressed by the lengthening of the steel rod. As the pendulum weighs nearly 4 cwt., the operation of setting it so that its vibrations might be correct to within a fraction of a second, was a matter of extreme difficulty. This was met by a contrivance suggested by Mr. Airy: the clock being started at a very small losing rate, a slender spring, so mounted as to touch the pendulum slightly, (and thus by slightly diminishing the amplitude of the arc cause the clock to gain,) was brought in contact with the pendulum-bob nearly at the centre of percussion, by means of a line in the clock-room. By this means the beats of a large turret-clock may be brought to coincide perfectly with those of a chronometer by which it is set. The regulating screw, by which the length of the pendulum is adjusted, is not moved for the correction of small errors in the rate of going, such being provided for by the use of small supplementary weights laid upon each side of the top of the pendulum-bob, which weights may be applied or removed without stopping the clock."

This clock has a remontoir escapement, and the pallets are jewelled with large sapphires. Mr. Airy's construction of the going-fusee is also introduced for maintaining the clock during the winding.

Electric Clocks. About the year 1840 Professor Wheatstone exhibited in the apartments of the Royal Society in Somerset House an *electro-magnetic clock*, the object of which was stated to be to enable a single clock to indicate exactly the same time in as many different places distant from each other as may be required. Thus in an astronomical observatory, every room may be furnished with an instrument of simple construction and at small cost, which shall indicate the time, and beat dead seconds audibly with the same precision as the standard astronomical clock with which it is connected; thereby obviating the necessity for having several clocks, and diminishing the trouble of winding up and regulating them separately. In like manner in public offices and large establishments, one good clock will serve the purpose of indicating the precise time in every part of the building where it may be required, and an accuracy insured which it would be difficult to obtain by independent clocks, without referring to the cost. In the clock exhibited, the parts connected with the maintaining and regulating power were dispensed with. It consisted simply of a face, with its second, minute, and hour hands, and of a train of wheels communicating motion

(1) Penny Cyclopædia, Supplement, Article "Horology."



HOROLOGY.—WORKING PARTS OF THE CLOCK AT THE ROYAL EXCHANGE, LONDON.

from the arbor of the seconds hand to that of the hour hand, in the same manner as in an ordinary clock train. A small electro-magnet was made to act upon a wheel placed on the seconds arbor, in such a manner that whenever the temporary magnetism was either produced or destroyed, the wheel, and consequently the seconds hand, advanced $\frac{1}{60}$th part of its revolution. Thus, by alternately completing and breaking the electric current every second, the apparatus described would perform all the usual functions of a perfect clock. The method of connecting this apparatus with a clock so as exactly to repeat the movements of its hands was as follows:—On the axis which carries the scape-wheel of the primary clock was fixed a small disk of brass divided on its circumference into 60 equal parts; each alternate division was then cut out and filled with a piece of wood, so that the circumference consisted of 30 regular alternations of wood and metal. An extremely light brass spring screwed to a block of ivory or hard wood, and not connected with the metallic parts of the clock, rested by its free end on the circumference of the disk. A copper wire attached to the fixed end of the spring proceeded to one end of the wire of the electro-magnet; while another wire, attached to the clock frame, was continued until it joined the other end of the wire of the electro-magnet. A constant voltaic battery of small size was interposed in any part of the circuit. Hence it will be seen that by this arrangement the circuit is periodically made and broken in consequence of the spring resting for one second on a metal division, and the next second on a wooden division. The circuit may be extended to any length, and any number of electro-magnetic clocks may be brought into sympathetic action with the standard clock.

Mr. Bain, Mr. Appold, and others, have also produced various forms of electric clocks, in which the current from the voltaic or *earth*[1] battery is made to supply the place of the spring or weight commonly used as the maintaining power. In these and other ingenious applications of electro-magnetism as a maintaining power to clocks, the attraction and repulsion of magnets have been brought to bear directly on the pendulum, the bob of which is a coil of insulated wire, through which the electric fluid is transmitted at intervals. While the current is being transmitted, the pendulum is attracted by the magnet and made to produce an oscillation, during which a pin, projecting from the pendulum rod, pushes a sliding bar from off certain conducting surfaces upon which it rests, and thus breaking contact the electric coil or bob loses its magnetism, and thus ceases to be attracted by the permanent magnet, which a moment before had deflected it; it, therefore, falls back into the vertical, and by its momentum performs the opposite oscillation: but in doing this, the pin again comes in contact with the sliding bar, and restores it into the position in which the circuit is completed; the coil is again electrified and consequently again in a condition to be attracted by the magnet: in swinging up to it contact is again broken; attraction again ceases; the pendulum swings back again, and in this way the pendulum is kept vibrating, and by its vibrations communicates motion to the escape wheel or other contrivance, and thence to the clock train.[2]

One of the latest arrangements of the electric clock is that contrived by Mr. Shepherd, of London, whose clock was shown on a large scale at the Exhibition. In applying electricity to produce the vibrations of the pendulum, the amount of power must be constantly varying with the variations of the battery, and it is of course impossible to obtain correct chronometrical results under such circumstances. Now it occurred to Mr. Shepherd that if, instead of applying the magnetic power directly to the pendulum, it were employed, on the principle of the remontoir escapement, to bend a spring to a certain fixed extent during each vibration, which spring in unbending should give the necessary impulse to the pendulum, the pendulum would thus be independent of variations in the electro-magnet, the function of which would be simply to bend the spring.

The three following figures (the drawings for which have been kindly supplied to us by Mr. Shepherd) will enable us to convey a correct idea of this ingenious

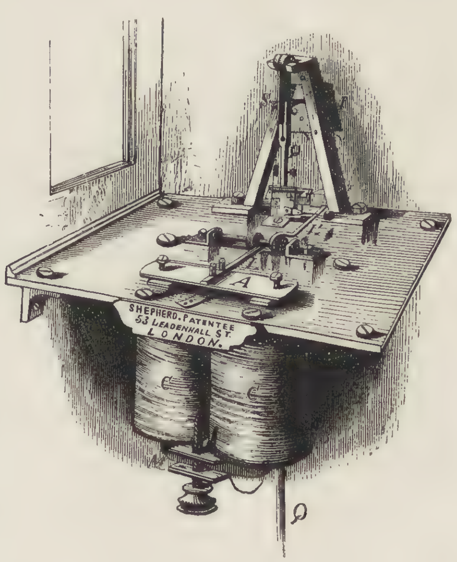


Fig 1184.

invention, which, unlike the previous electric clocks, aims at being itself a perfect time-keeper. It should be stated that in this arrangement the *pendulum*, the

(1) The earth battery, as usually made, consists of a large plate of zinc, and either a plate of copper or a quantity of coke, buried at a certain distance asunder in damp earth. The moisture of the earth acts on this voltaic couple as the exciting fluid, and a feeble but very constant current is produced by this arrangement.

(2) In our articles Electric Telegraph and Electro-Motive Machines a variety of contrivances for producing motion by electricity, and for closing and interrupting the current, will be found described. In the article Electro-Metallurgy various forms of voltaic battery are described.

clock train and the *striking part* has each its own separate and distinct system of electro-magnets and voltaic battery, so that the pendulum may continue to vibrate although the clock train be at rest, the train being set in motion by its own electro-magnets under the regulating influence of the pendulum. The striking part is also under the control of the pendulum and the train, although moved by its own electric power. It is one of the peculiarities of Mr. Shepherd's clock, that the pendulum does not depend for its motion, as in ordinary clocks, upon the clock train, nor does it constitute the maintaining power, as in Mr. Bain's clock. The pendulum may be quite detached from the other portions of the clock, and may, indeed, be used for a great number of clocks in simultaneous action.

Fig. 1184 shows the pendulum Q Q suspended from a triangular framing and passing through a hole in the bed plate. M is a horse-shoe of soft iron each limb of which is surrounded by a coil of wire, C C, one of the extremities of this compound coil terminating in the metal bed plate, and the other in the triangular framing at I, in a slight spring tipped with platinum and insulated by an ivory mounting. The swinging of the pendulum to the right completes the circuit, and converts M into a powerful magnet. The two ends or poles of this magnet pass through the bed plate and rise a little way above its surface. A is an armature of iron which is attracted down to the poles of the magnet whenever an electric current is circulating in the coils, C C, and is detached therefrom by a weighted lever L L′ as soon as the current is interrupted. The lever L L′ is attached at right angles to a short axis, the extremities of which move in two brackets, so as to raise the lever a little way above the bed plate: to the extremity of the arm L′ is fixed a weight, which is better shown at W, Fig. 1185, to which we will now refer, this figure representing on a larger scale similar parts of Fig. 1184. (In this figure, however, L should be L′.) E E′ is called the *impulse spring*, and D D′ a *detent* or *catch* for holding this spring when bent by the action of the magnet. Now the action is as follows:

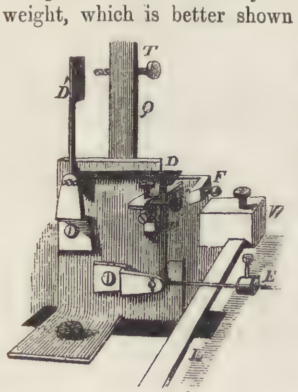


Fig. 1185.

—Supposing the pendulum to have swung to the right by a force which we will explain presently, it touches the insulating spring I and closes the circuit; whereupon M becoming magnetised by the passage of a current through C C, the armature A is attracted down, the effect of which is to move the weight W up, and in doing so it will raise the arm E′ of the spring or right-angled lever E E′, which moves upon a centre at its right angle, and in doing so will lock another right-angled lever D D′, leaving it in the position shown in Fig. 1185. But by the time the detent is locked, the pendulum, which we have supposed to have swung from left to right, falls back into the vertical by the action of gravity alone, and by its momentum is carried to the left; contact is broken at I; M ceases to be a magnet; the weight W falls down and raises the armature A from the magnet, leaving E′ free to fall when E is unlocked at D. Meanwhile the pendulum goes on swinging to the left, and soon causes the banking screw T to strike against the discharging pallet D′ and unlock the detent: the arm or lever E thereupon falls down upon the impulse pallet F, and gives the pendulum its impulse back again from left to right with a force just sufficient for it to continue its vibration. Thus it will be seen that the periodical falling of the spring E E′ gives the impulse to the pendulum from left to right; that the making contact while the pendulum is at the right has the effect of restoring the spring E E′ to its position preparatory to another fall; that the swinging of the pendulum to the left breaks contact, and by raising D allows E E′ to make another fall. In this way the action proceeds, the electro-magnet being used for the sole purpose of restoring the spring to the position shown in Fig. 1185; it evidently does not matter how much the magnet M may vary in intensity provided it be not too weak to pull down the armature A, and it is an advantage to employ an excess of magnetic power in machines of this kind.

In order to move the clock train and the hands H H, Fig. 1186, on the dial plate, there are a pair of pallets P, taking into the teeth of the escape-wheel at right angles, to which are fixed two or more bar magnets B B. Immediately under or over each of the

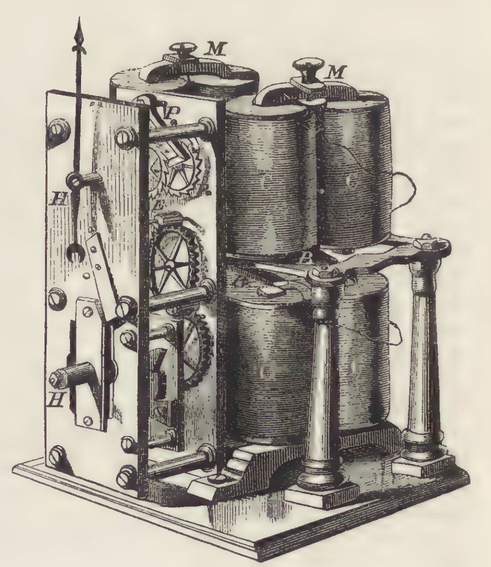


Fig. 1186.

poles of these bar magnets is the pole of an electro-magnet M M. These electro-magnets are caused alternately to attract and repel the bar-magnets,

thereby imparting an oscillating motion to the pallets, which act in the teeth of the escape-wheel E, and drive it forward: the motion thus produced is carried through a train of wheels in the usual way. In producing the electric currents required, two contact-springs and two batteries are employed: the contact-springs are mounted on an ivory bracket, one spring on each side of the pendulum-rod, with which their points make contact close up to the centre of motion, at the end of the vibrations of the pendulum each way. The batteries are arranged in connexion with these springs, so that the circuit of each battery shall be in a contrary direction to the other. Consequently, as the pendulum vibrates to the right, it completes the circuit of one battery; the electricity passing through the coils of the electro-magnets, they cause one oscillation of the bar-magnets. On the opposite vibration of the pendulum, it makes contact with the opposite spring, the battery in connexion with this being arranged in a contrary direction to the former; the electricity passes through the coils of the electro-magnets in a contrary direction, causing an opposite oscillation of the bar-magnets, and consequently of the pallets, which, operating on the teeth of the escape-wheel, drive it forward.

Mr. Shepherd in his paper on this subject, read before the Society of Arts 26th February, 1851, states, that this method of using attraction and repulsion has two advantages. It admits of electro-magnets being used of such size, that about 2,000 feet of wire may be wound upon them, whereby a great saving in the batteries is effected. It also insures great certainty in the action with the smallest possible power, since the power applied to move the pallets is nearly equal throughout the extent of their motion. By using two batteries, reversed currents may be produced with only one spring on each side of the pendulum, while to reverse the connexion of one battery, two springs would be required, which would be more disadvantageous.

The application of the electro-magnetism to the striking part is thus effected: the escape, or seconds-wheel is furnished with a projecting pin, which is thus carried round once in a minute. The minute-wheel, carrying the minute-hand, has a similar pin, which only completes its circuit once in the hour; in consequence of which the two pins are in conjunction only once in that time, namely, exactly at the hour. On an arbor in the frame of the clock is fixed an elastic arm, which is insulated from the arbor by an ivory bush. This arm carries at its extremity a small pad or table of platinum, on which, if it be sufficiently raised, the pin of the escape-wheel rubs in passing. The arbor also carries a rigid arm in such a position that the pin in the minute-wheel lifts it as it passes each hour; but the arm cannot be raised without the elastic arm, also carried by the arbor, being lifted, by which the platinum table at its extremity comes into contact with the pin in the seconds-wheel,—an occurrence which takes place at the hour, the hands being properly adjusted to that end. By so doing, it completes the circuit of a battery, which has one pole connected with the clock-frame and the other with the coils of the electro-magnet. Now, the only break which exists in this circuit is at the small platinum pad; when, therefore, at the completion of each hour, the pad and the pin are in contact, the circuit will be rendered complete. The magnet is thus rendered active, and by its attraction draws down the armature. The armature is situated at one end of a lever, the other end of which carries a detent, which is received into the notches of the locking-plate. When the armature is drawn down (in other words, when the circuit of the battery is complete at the end of each hour), the detent is drawn out of the notch, and the locking-plate left free to revolve. The raising of this detent forms a contact between a wire from another battery and the clock-frame. This battery actuates a magnet, which works the actual striking apparatus. The circuit is completed through the clock-frame and through the bar-magnets, formerly described as oscillating once in every second, one end of which as it rises touches a stud immediately over it, at the end of the other wire of the battery. This magnet, being therefore rendered active once in every two seconds, while the locking-plate is free, alternately attracts and repels one end of a lever, to which is attached the hammer; the other end taking into a ratchet and click arrangement, which allows the striking to continue as long as the locking-plate is free.

We have already seen that the inventor of the electric clock in 1840, proposed by this instrument to publish the precise time in every part of a large observatory, or other establishment. By an extension of the idea it is proposed in 1852 to connect all the railway stations in the kingdom with a great central clock, placed in communication with the Greenwich electric clock, which is so constructed as to transmit time-signals every hour and half hour throughout the day all over the kingdom. These signals will be received at the central telegraph office in London, and be despatched down the different lines of railway in succession, one at one hour and another at the next hour. At one o'clock no time-signal will be sent, but at that hour precisely the electric clock will drop the time-ball at the Royal Observatory, to enable ships in the river to adjust their chronometers. Time-balls will also be erected on the roofs of the telegraph offices. As it is now becoming customary to set all the clocks in the kingdom to Greenwich instead of local time, the carrying out of this idea will be of great value. By means of the electric clock it is also proposed to transmit time signals from one observatory to another, and thus test some interesting problems respecting longitude, &c.

HORSE-HAIR. See Hair.

HORSE-POWER. A term introduced by Watt, to enable him to determine what size of steam-engine should be sent to his customers on their informing him how many horses they were accustomed to employ to do the required work. It was found by experiment that the average force exerted by the strongest horses at one of the London breweries was equal to 33,000 lbs. raised 1 foot high in a minute,

and this was taken as equivalent to 1-horse-power. Since the time of Watt, however, the capacity of cylinder answerable to a horse-power, and the pressure on the piston, have been increased, so that at the present time a horse-power is a mere conventional unit for expressing a certain size of cylinder without reference to the power exerted. See STEAM-ENGINE.

HOSIERY. See WEAVING.

HOT-BLAST. See IRON.

HYDRATES, combinations of water with other oxides. For example, when a small quantity of water is poured upon lime (which is oxide of calcium), a portion of the water combines therewith, forming a bulky white powder, which is hydrate of lime (CaO, HO). In the formation of hydrates the action is often very irregular, and the temperature is greatly raised, as in the slaking of lime, the example just given. The attraction between the water and the second body is often so strong that it cannot be separated by the application of heat. The hydrates of potash, of soda, and of phosphoric acid, are examples of this; so also is oil of vitriol, which is a hydrate of sulphuric acid.

HYDRAULICS. See HYDROSTATICS and HYDRODYNAMICS.

HYDRAULIC-PRESS. See HYDROSTATICS.

HYDRIODIC ACID. See IODINE.

HYDROCHLORIC ACID, (HCl. 37). This important acid belongs to the class of hydrogen acids or hydracids, which do not exist in salts. It has long been known in solution in water under the names of *spirit of salt, marine acid,* and *muriatic acid,* (from *murias,* sea-salt.) In its pure form it is a gas, which may be formed by mixing together one volume of hydrogen and one of chlorine, and exposing the mixture to the light of day, when the gases slowly combine, and produce two volumes of hydrochloric acid gas; but if exposed to the direct rays of the sun, the gases combine with an explosion: such also is the case when an electric spark is passed through the mixture. Hydrochloric acid gas may however be easily prepared by heating in a flask, fitted with a cork and a bent tube, a mixture of common salt and sulphuric acid diluted with water:[1] the gas, which must be collected over mercury, is colourless; it produces a white cloud or fume in the air in consequence of its strong affinity for moisture; it has an acid suffocating odour, and can be liquified under a pressure of 40 atmospheres. Its density is 1·269: it is so soluble in water that at the temperature of the air that liquid dissolves about 418 times its bulk of the gas. The solution is powerfully acid.

The muriatic acid of commerce is prepared by decomposing common salt with sulphuric acid and receiving the gas in water. The materials employed, and the products, may be stated in another form:—

1 equivalent of chloride of sodium	60
1 equiv. of sulphuric acid 40, containing 1 equiv. of water 9	49
	109
PRODUCTS.	
1 equiv. of sulphate of soda	72
1 equiv. of hydrochloric acid	37
	109

In order to condense the hydrochloric acid, 6 equivalents of water = 54 are used, which, added to the equivalent of acid = 37, give 91 of liquid acid: so that supposing the operation were conducted without loss, 60 parts of common salt will give 72 of sulphate of soda, and 91 of muriatic acid.

There are several methods of preparing the acid on a large scale. In places where glass can be had at moderate cost large glass retorts are used. The salt is first introduced, and then the acid, in such a way, by means of a long funnel, so as not to soil the neck. The beak of the retort is then introduced into a large globular receiver D, Fig. 1187, from which a tube passes into a Woulfe's bottle E,[2] and this

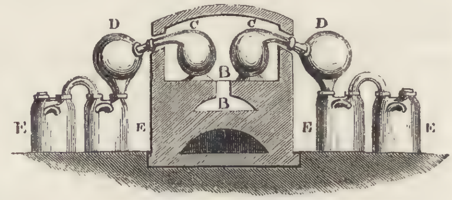


Fig. 1187

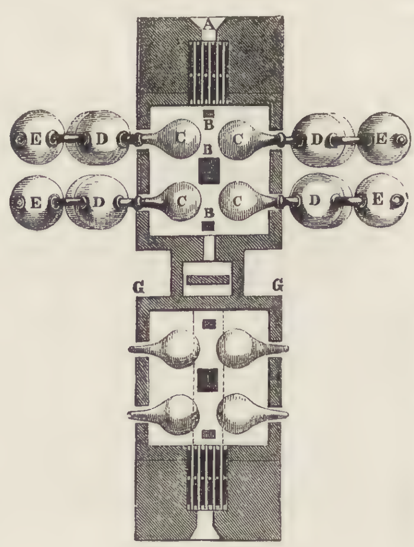


Fig. 1188.

is connected by a bent tube with a second bottle, the second with a third, and so on; by which means the acid may be obtained of different degrees of purity. The first bottle, which contains no water, retains the

(1) The action may be thus explained:—

Chloride of sodium { Chlorine — Hydrochloric acid.
{ Sodium

Water { Hydrogen
{ Oxygen

Sulphuric acid — Sulphate of soda.

(2) Woulfe's apparatus is more particularly described in the article DISTILLATION, vol. i. p. 497.

impure portions of the acid, and the vapour then passes from it into the second, third, and other bottles, which contain a supply of water for condensing it. That portion of the vapour which escapes condensation in the bottles is passed by a tube into a vessel of water. The condensation is instantaneous, or nearly so, but as the temperature rises less gas is absorbed; hence the condensing vessels should be kept cool. The retorts, 4, 6, 8, or 10 in number, are arranged in the vault of a furnace, B C, in two rows, as shown in Fig. 1188, and are heated by the hot air from the furnace A, which, by an arrangement of the brickwork, is made to circulate round the retorts on its passage to the chimney G, and in order that the drafts of the two contiguous furnaces may not interfere with each other, the chimney for some way up is divided by a partition wall.

Muriatic acid is also manufactured on the large scale by using iron cylinders for the retorts. Alkali works, in which common salt is decomposed for the manufacture of carbonate of soda, produce enormous quantities of muriatic acid as a waste product, and, passing up the chimney, it may be seen condensed by the atmospheric moisture hovering over it in the form of a white cloud, which, wafted away by the wind, produces a corrosive rain, which ruins the vegetation of the surrounding district. Of late years, however, this acid has been turned to profitable account. [See SODA.]

When the solution of muriatic acid gas is pure, it is transparent and colourless: when saturated with the gas it has a sp. gr. of 1·21, and contains about 42 per cent. of real acid. The commercial acid is impure: it has a yellow colour, and contains sulphuric acid, chloride of iron, and organic matter. It may be purified by mixing with water and distilling.

HYDROCYANIC ACID. See PRUSSIAN BLUE.

HYDROGEN, (from ὕδωρ, water, and γεννάω, to produce,) one of the constituents of water. Its symbol is H, and its atomic or combining number 1. It may be procured by passing vapour of water through an iron or porcelain tube, containing, in the middle part, a quantity of iron turnings heated to redness by fixing the tube across a furnace. The oxygen of the vapour of water combines with the iron, while the hydrogen passes off in a permanent form, and may be collected and examined.

Hydrogen may be abundantly collected by the action upon each other of zinc, sulphuric acid, and water: the oxygen of the water unites with the zinc, forming oxide of zinc, which is instantly dissolved by the acid, while the hydrogen of the water is set free in the gaseous form.

Hydrogen, when quite pure, is colourless, tasteless, and inodorous. It is inflammable, burning when kindled, with a pale-yellowish flame, giving out much heat, but very little light, the result of the combustion being water. It is not soluble in water, and it has never been liquefied. It is the lightest substance known, its sp. gr. being between ·0691 and ·0695. Under ordinary pressure and temperature 100 cubic inches weigh 2·14 grains.

Although hydrogen is of first-rate importance in the economy of nature and in chemical science, it has but very few applications in the useful arts. Perhaps its most useful industrial applications are in what is called *autogenous soldering* [See SOLDERING], and in restoring to the metallic state copper turnings which have become oxydized. For this purpose they are heated in a tube, and a stream of hydrogen passed over them, which combines with the oxygen and revives the copper. Hydrogen may also be used for filling balloons in places where coal-gas is not to be had; and it may be employed in conjunction with spongy platinum in an instantaneous-light apparatus, Fig. 1189, the construction of which is ingenious. It consists of a glass vessel A, into which passes the stem of a glass globe B, fitting air-tight at the neck of A. B is also furnished with a tight stopple *s*. From the side of A proceeds a short pipe furnished with a stop-cock C, opposite the jet of which is mounted, upon a bent wire, a ball of spongy platinum. Upon the stem of B a piece of thick zinc tube Z is fixed by means of a ring of cork *e* at the bottom. The vessel A is about 3 parts filled with water acidulated with sulphuric acid. On putting the stem into the bottle, opening C, removing S, and turning away *p*, which may be done by means of the joint *j*, the action is as follows:—Hydrogen-gas will be generated, and rising to the top of the vessel A, will pass out through C, and escape, taking with it the air left in the vessel. If C be now closed the hydrogen will accumulate in A, and by its pressure force the acid water up the pipe into the globe B, gradually uncovering

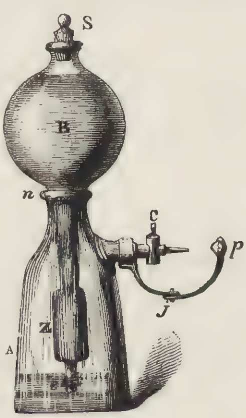


Fig. 1189.

the zinc until it is left quite dry, when of course the generation of the hydrogen ceases. If now we bring the spongy platinum round before the jet C, and open the stop-cock, the hydrogen streaming upon the finely-divided platinum, the latter will cause the hydrogen to unite with the oxygen of the air, the effect of which will be to raise its temperature to redness, and thus to set fire to the jet of gas issuing from the stop-cock. From this ignited jet a taper or a match-paper may be lighted. While the gas is issuing from C, acid descends from B into A, and gradually covers the zinc: thereby keeping up the supply of gas; but on closing C the gas drives the acid back again into B, and the zinc is again left dry. This apparatus may be made ornamental in form, and small in size.

HYDROMETER. See GRAVITY, SPECIFIC.

HYDROSTATICS and HYDRODYNAMICS, form the third and fourth of the great divisions of the Science of Mechanics. The one, which considers

the laws of water in a state of rest, is derived from ὕδωρ, water, and στατὸς, standing still; and the other, which takes account of the laws which regulate water in a state of motion, is from ὕδωρ, and δύναμις, force. The latter is also termed HYDRAULICS.

The properties of liquids are always modified by the action of two forces; viz. that of weight, or the attraction of gravitation, to which they, in common with matter of all kinds, are subject; and, secondly, molecular attraction, which must act differently in liquids and solids, although we have no means of determining in what this difference consists. We can readily form an idea of the distinct action of each of these forces, for we can imagine a mass of water ceasing to be heavy without ceasing to be liquid; such a mass would neither fall nor flow when turned out of the vessel containing it, and indeed it would not require for its equilibrium to be sustained by the ground, or even by a vessel; and yet such a mass of weightless fluid would display a number of remarkable properties, the most important of which would be equality of pressure in all directions; that is to say, the liquid would transmit equally, and in all directions, any pressure exerted on its surface. For example, let *a b c d e f*, Fig. 1190, be a vessel containing a liquid supposed to be without weight, and P a solid piston, which exactly covers its surface. If the piston be also without weight, it is clear that the liquid experiences no pressure, and that if a hole were made in the vessel no portion of the liquid would flow out. Now, suppose that the piston be loaded with any given weight, say 100 lbs, it will of course tend to sink down into the liquid, and it would do so unless the liquid itself opposed such a tendency. Whether the liquid be compressible or not, the result is the same, for the liquid must either become annihilated, or it must bear up the weight of 100 lbs. If we divide the liquid into any number of layers, the uppermost layer, which is in contact with the piston, and sustains it, also sustains the whole of the weight, and would of course descend unless supported by the layer immediately beneath, which receives from the one above it as much pressure as that one receives from the piston. So also the second layer presses upon the third, and in this way we may go on until we arrive at the bottom of the vessel, which we shall find has to sustain the pressure of the 100 lbs. exactly as if the weight and piston were placed there instead of being transmitted by the liquid Now, as this pressure of 100 lbs. is borne by the whole of the base of the vessel, it is evident that one-half of the base sustains only 50 lbs., and that one-hundredth part of the base sustains only 1 lb. We see, then, from this illustration, 1st, That the pressure is transmitted by horizontal surfaces from the top to the bottom of the vessel without any loss of effect; 2d, That the pressure is equal at each point; 3d, That it is proportional to the extent of the surface under consideration.

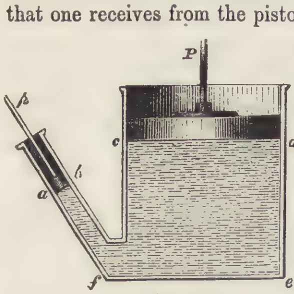


Fig. 1190.

So far we find no difference between a liquid and a solid, but the peculiar characteristic of liquids is, that the same effects are produced on the *sides* of the vessel as on the base. If a lateral opening be made in any direction, as at *a b*, the liquid will spirt out; and if the opening thus made be of the same size as the piston P, it will require a force equal to 100 lbs., to prevent the water from spirting out; if this side opening be only one-hundredth of the area of the piston, the water may be kept back with the force of 1 lb. If a hole be made in the piston, the liquid will spirt upwards, proving that the piston also sustains a pressure similar to that on the base and sides of the vessel. Indeed, this necessarily arises from the principle of action and reaction. It will be seen that liquids transmit equally, and in all directions, the pressures exerted on any part of them, so that every surface which they touch receives (and must return) a pressure proportioned to its area. Thus, if the area of the piston P be, as we have supposed, 100 times that of the piston *p*, it will require a pressure of 100 lbs. on P to balance 1 lb. on *p*. Thus we have another simple machine, like those commonly called MECHANICAL POWERS. And this *hydrostatic power*, no less than the others, depends on the principle of virtual velocities [See MECHANICS]: for it is evident that if the piston *p* be pushed in through any given distance, the piston P, which is 100 times larger will be thrust out only $\frac{1}{100}$ of that distance, so that whatever may be the gain of power, it is procured by an equivalent loss of motion. Used as a press (Bramah's press) this machine has some great advantages over the wedge or the screw, as its mechanical efficacy can evidently be increased to almost any extent without any proportionate increase of friction or complication of parts.

Now it must be evident that this property can be in no way altered by conferring weight on the liquids under consideration, except that additional forces arising from the mutual weight and pressure of the particles have to be taken into account. Whence it follows, that in order for a liquid to be in equilibrium, two conditions are necessary; first, every point of its surface must be perpendicular or normal to the force which acts upon it; and, secondly, each individual particle of the liquid must experience equal pressures in all directions.

With respect to the first condition ot equilibrium, let us suppose that the surface is not perpendicular to the force which acts upon the liquid particles; that this surface follows the direction *a c d e*, Fig. 1191, while the force acts in the direction of the vertical lines V V. In such case a horizontal layer *b d* must be pressed by the weight of all the particles above it; and this pressure being, as we have seen, transmitted laterally, the molecule *d*, for example, would be thrust out by this lateral pressure, since there is no counterbalancing pressure on the opposite side; it

is thrust aside, and another particle occupies its place, which, in its turn, is also thrust aside until at length the particles forming the curve *a c d*, have fallen into the depression *d e*, and the whole surface has become horizontal. The same process would take place with any other portion of the liquid above the horizontal surface, and there can be no equilibrium until there are no more particles to descend; when such is the case, they are all ranged in a plane normal to the force.

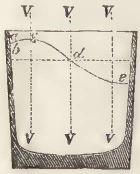


Fig. 1191.

From the principle of equal pressures, as well as from the first condition of equilibrium in liquids, many important consequences are obtained. For example, the pressure of water and other liquids upon a given surface, is in proportion jointly to the magnitude of that surface and to the mean height of the liquid above that surface.[1] This truth is readily understood in the case of a cylindrical vessel, such as No. 1, in Fig. 1192, but it is not so evident in the vessels No. 2 and No. 3. All three vessels contain very unequal quantities of water; they differ in every respect except being of equal height and base; and in each case the same amount of pressure is exerted on the base without any regard to the bulk of the water. Hence we may estimate the pressure of a fluid upon the base of the containing vessel by multiplying its height into the area of the base, and this product by the density of the fluid. In the vessel No. 2 it will be seen that the bottom bears only the column of fluid denoted by the dotted lines, and which is exactly equal to the whole fluid in No. 1. But however paradoxical it may appear, it is no less true, that the base of No. 3 bears a pressure exactly equal to this same weight of fluid, although the whole vessel does not contain so much.

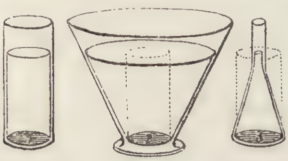


Fig. 1192.

Fig. 1193.

Some curious results may be obtained by the operation of this law. Let a vessel, A, Fig. 1193, full of water, have a slender tube, B, screwed into it: on filling the tube with water to a certain height, the vessel will immediately burst; and the height of the fluid necessary to effect this result will be exactly the same, however large or however small the tube may be; so that the weight of a single ounce of water, if piled high enough, may burst the strongest vessel. Suppose the bore of the tube to be one-twentieth of an inch, then whatever pressure is transmitted through it, an equal pressure will be borne by every space one-twentieth of an inch in diameter throughout the interior of A. Now a square inch contains about 530 such spaces; so that an ounce of water poured into such a tube would exert a pressure of 530 ozs., or 33 lbs., on every square inch of A; a force which few vessels, except steam-boilers, are made capable of resisting.

Thus the whole interior surface of a vessel is subject to an enormous pressure in consequence of the manner in which liquid pressure is transmitted. And not only the interior surface, but the liquid particles also in every part of the vessel, are subject to corresponding pressures. In the interior of the liquid mass contained in the vessel shown in Fig. 1194, let us imagine a layer, *l l*, parallel to the surface S S. All the particles of this layer are evidently pressed by the mass of liquid above them; they are, as it were, under the pressure of a liquid cylinder, S S *l l*. But it is important to observe that this pressure from above, downwards, is, by the principle of action and reaction, exactly equal to that from below, upwards; and the separate molecules of this layer *l l* are held in equilibrium by these equal and opposite pressures. Now, in limiting our attention to a portion only of this layer, *a b*, it will be seen that the surface *a b* is at once pressed from above, downwards, by the liquid column *c d b a*, and from below, upwards, by a precisely equal force; so that if a solid were plunged into the water whose base exactly occupied *a b*, this pressure would act upon the solid from below, upwards, tending to drive it out of the liquid.

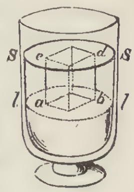


Fig. 1194.

This will be clear from the following experiment:—A tolerably large glass tube, *t*, Fig. 1195, ground flat at its lower extremity, is closed by means of a glass plate or valve, *v v*, from the centre of which proceeds a string up to the top of the tube. If the surfaces be tolerably smooth, the valve will close the tube water-tight on pulling the string. On lowering the tube thus closed into the vessel of water, A B C D, the thread can be let go, because the valve will be upheld by the upward pressure of the water; and that this pressure is equal to that which it would sustain at that depth from a column of water acting from the surface, downwards, is proved by pouring water into the tube. As soon as the interior level approaches the exterior *a a*, the glass valve is pressed from above as much as it was before pressed from below, and it then falls to the bottom of the vessel by its own weight: or rather by the difference between its weight and that of an equal bulk of water, for it cannot descend without raising such a quantity of water, just as the heavy arm of a balance cannot descend without raising the lighter arm.

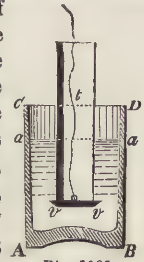


Fig. 1195.

(1) That is, its height above the *centre of gravity* of the surface.

The pressure, then, upon a given surface, is the same, whether it face upwards or downwards; and may also be proved to be the same in whatever direction it be turned, provided its centre of gravity remain at the same depth below the liquid surface; for this pressure is equal to the weight of a column of liquid whose base is the given surface, and whose length equals the depth of its centre of gravity.

In water, the pressure on any surface at the depth of 1 foot is equal to nearly half a pound on the square inch. At 2 feet depth it is about 1 lb. At 3 feet = $1\frac{1}{2}$ lb. At 4 feet = 2 lbs. At 5 feet = $2\frac{1}{2}$ lbs. In a cubical vessel full of a liquid, the pressure on any one side is equal to one-half the pressure on the base; for the bottom sustains a pressure equal to the whole weight of the fluid, and the pressure sustained by each side is equal to the weight of a mass as long and broad as that surface, and as deep as its centre, and, consequently, equal to half the contents of the vessel. Hence we get the remarkable result that, in a cubical vessel, a liquid produces a total amount of pressure 3 times as great as its own weight; for if this equal 1, and the pressure upon each of the 4 sides be equal to half that upon the base, then $4 \times \frac{1}{2} = 2$ and $2 + 1 = 3$.

In any surface which sustains the pressure of a mass of fluid, there is a point called the *centre of pressure*, at which the whole pressure of the mass may be conceived to act, and to which, if a single sufficient force were applied, the mass of fluid would be supported, and the surface kept at rest. In any vertical surface extending to the top of the fluid, this point is at one-third the depth of the fluid from the bottom, and at the middle of the breadth of the surface. The determination of this point is of the highest importance in all works made to resist fluid pressure.

When a number of vessels communicate with each other, whatever be their form or size, the same conditions of equilibrium apply to the fluid contained in them as to a single vessel. In the first place, the surfaces of the fluid in the vessels are all *level;* and, secondly, they are all *at the same level*, provided the same fluid be used. Thus, on filling the large vessel A with water, or mercury, or any other fluid, it will exert a pressure on the side tube, near the bottom, equal to the area of the tube × by the height, × by the density of the fluid; and on opening the stop-cock *c*, this pressure will cause the fluid to ascend into the small vessel B until it attains the same level as in A, when equilibrium will be established, because the water in A, as well as the water in B, presses upon the same space at *c*, and both are of the same height.

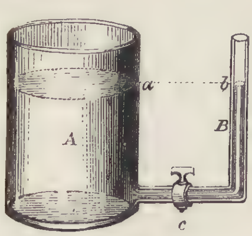


Fig. 1196.

If fluids of different densities, such as water and mercury, be made to communicate, the height to which they will rise in the limbs of a vessel such as A B, Fig. 1197, will be respectively in the inverse ratio of their densities. If the bend be first filled with mercury, and water be then poured into A, a column of that fluid, 13·6 inches high, will be necessary to balance 1 inch of mercury in B, mercury being $13\frac{6}{10}$ times denser than water. It matters not how unequal in bore may be the two branches of the tube: if the experiment be repeated in such an apparatus as Fig. 1196, the result will be the same, whether the mercury be in A or in B; the whole height of water will always be 13·6 times that of the higher mercurial level above the lower.

Fig. 1197.

The *densities* or *specific gravities* of different bodies are usually compared with water as a standard, on what is sometimes called the *principle of Archimedes*, namely, that when a solid is immersed in a fluid, it displaces a quantity of the fluid exactly equal to its own bulk. If the quantity of fluid thus displaced be lighter than the solid, the solid will sink in the fluid; if it be of the same weight, it will rest indifferently in any part of the fluid; if heavier, it will float in such a manner as to displace only as much fluid as may equal its own *weight.* But confining our attention to the first case (of a body that sinks), the body thus immersed in the fluid apparently loses a portion of its weight exactly equal to that of the fluid displaced, as the following experiment will prove. A solid cylinder of copper S, Fig. 1198, exactly fitting into a hollow cylinder C of the same material, are both suspended from an arm of a balance, and brought into equilibrium by weights in the opposite scale-pan P. The solid cylinder is allowed to dip into an empty glass. On filling up this glass with water, so as completely to immerse the solid cylinder, the scale-pan P will sink down in consequence of the apparent loss of weight in the cylinder S. Now, on filling up the hollow cylinder C with water, the balance is restored. The fluid support which is given to S is represented by the weight of the water in C required to restore the equilibrium of the balance; and as S exactly fits into C, the bulk of water poured into C must be exactly equal to that displaced by S. And this would be true, whatever might be the material of S, whether gold or cork. If it were cork, it would appear to lose more than its whole weight, or to acquire, when immersed, a levity or upward tendency, which, however, is still found to be neutralized, and its exact weight restored,

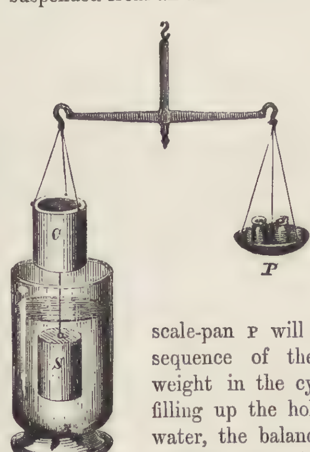


Fig. 1198.

by filling C. It is scarcely necessary to observe, that all apparent instances of a tendency the reverse of gravity, as in smoke, balloons, &c., are only effects of this kind depending on the pressure of the surrounding fluid, which must be denser than the rising body.

The method of taking the specific gravities of bodies is described under GRAVITY SPECIFIC. When a body *floats* on a fluid, it displaces a quantity equal in *weight* to itself; when it *sinks*, it displaces a quantity equal in *bulk*. Hence the conditions of equilibrium in floating bodies are two:—1st. That the portion immersed : the whole bulk : : the density of the solid : that of the fluid. 2d. That the centre of gravity of the solid, and that of the fluid displaced, are in the same vertical line. The equilibrium, however, may be stable or unstable; and if stable, the body will, on being disturbed, return to its former position by a number of oscillations which are isochronous, like those of the pendulum; and their times depend on the position of a point called the *metacentre*, which has the properties of the *point of suspension* in pendulums. When the metacentre is *lower* than the centre of gravity of the whole body, the equilibrium is *unstable;* otherwise it is stable.

The principles which regulate the motions of fluids constitute the science of *Hydrodynamics* or *Hydraulics*. This subject is one of great complexity, on account of the facility with which a fluid mass is set in motion by the disturbance of a few only of its particles; and the resulting motions are modified, either in their velocity or in their direction, by so many causes, that it is difficult to anticipate or explain the various phenomena which arise. There are, however, in this science certain fundamental laws which go far to generalize the phenomena.

The sides of a vessel containing a fluid are subject to two opposite forces—one arising from the hydrostatic pressure of the fluid, tending to burst the vessel outwards; the other, from the atmospheric pressure, or that of any other medium surrounding the vessel, tending to burst the vessel inwards. If an opening be made in the side or base of the vessel, the liquid will flow out, provided the interior pressure be greater than the exterior. In the common trick of covering a glass quite full of water with a piece of paper, and inverting the glass without spilling the water, the atmospheric pressure is greater than that of the water, and would continue to be so if the glass were 32 feet in depth. If the mouth of the glass be small, as in a narrow-necked phial, no paper need be used, for, on inverting it, the pressure of the air on the mobile but narrow surface of the fluid will prevent it from flowing out without dividing, which its cohesion prevents it from doing. If the neck be enlarged, the air, being so much lighter than the water, will force a passage up through it, and break up the liquid column. But if an opening be made in the top of the vessel, the liquid will flow smoothly, as if no air were present; for the atmospheric pressure, together with that of the fluid *within*, is opposed to the atmospheric pressure alone *without;* and the motion is produced by the difference of these pressures, viz. that of the liquid alone.

In the examples which we are about to consider of liquids escaping from an orifice, the flow will result from excess of pressure, and not from the breaking up of the liquid column. But, in order that results may be comparable, it is necessary that the surface of the liquid in the containing vessel be maintained at the same height by some contrivance which shall add to the vessel the same amount of liquid as flows from it. In such case, neglecting all mechanical obstacles arising from friction and other causes, the flow of liquids from orifices in vessels obeys the force of gravitation, and their motion becomes accelerated, according to the law of falling bodies. The expression of this law, known as *Torricelli's theorem*, is, That particles of fluid, on escaping from an orifice, possess the same velocity as if they had fallen freely *in vacuo* from a height equal to that of the fluid surface above the centre of the orifice.

All bodies falling from the same height *in vacuo*, acquire the same velocity; but the flow of liquids from an orifice does not depend upon their densities, but only on the depth of the orifice below the level of the fluid. Mercury and water, for example, flow with the same velocity when they escape by similar orifices at the same depth below their levels; for although the pressure of the mercury is $13\frac{1}{2}$ times greater than that of the water, it has $13\frac{1}{2}$ times as much matter to move.

The velocities acquired by falling bodies are as the square roots of the heights; so that in order to produce a twofold velocity, a fourfold height is necessary, &c.; so also in the escape of liquids from an orifice, the velocities are as the square roots of the depths of the orifices below the surface of the fluid; so that, if we wish to double the velocity of discharge from the same orifice, a fourfold depth is required; to obtain a threefold velocity, a ninefold pressure is necessary, and so on. Because, in an equal time, *thrice* as much matter has to be moved with *thrice* as much velocity.

When a vessel with vertical sides is allowed to empty itself by an orifice in the bottom, the quantities flowing out in successive equal intervals are as a diminishing series of odd numbers (as 9, 7, 5, 3, 1), or as the spaces described in equal intervals by a falling body, *taken backwards.*

In such cases there forms, after a certain time, a hollow depression on the surface immediately over the orifice; this increases until it becomes a cone or funnel, the centre or lowest point of which is in the orifice, and the liquid flows in lines directed towards this centre.[1] Of course, the issuing stream or vein is vertical if the orifice is at the bottom of the vessel, or it describes a parabolic curve if the orifice is at the side. In either case it moulds itself, as it were, to

(1) In this state of the liquid a rotary motion is imparted to it, and rapidly increases, because all the particles are approaching the centre; and by virtue of their inertia they tend to maintain the same velocity which they had in a larger circle, so that their angular velocity (or the number of revolutions in a given time) is constantly increased.

the form of the orifice, and extends to a considerable distance before it scatters and divides into drops. Between the mouth of the orifice and the point where it begins to divide, the liquid vein has a permanent form, and a polished surface; and notwithstanding the rapid motion of the liquid particles which succeed each other incessantly, the jet has the appearance of a perfectly motionless rod of glass. At the commencement of its course, the vein is of the same diameter as the orifice, but for a short distance its diameter grows less, forming what is called the *vena contracta*, or contracted vein of fluid, Fig. 1199. The reason for this contraction appears to be, that as the liquid particles approach the orifice, they converge to a point beyond it, so that the liquid column in escaping must necessarily be narrower or more contracted at the point towards which the motion of the liquid converges, than it is either before it arrives at that point, or after it has passed it. The greatest contraction of this fluid vein is at a distance from the orifice equal to half its diameter; the diameter of the contracted portion being to that of the orifice as 5 : 7. Hence the real discharge of fluid is only $\frac{25}{49}$, or about half of the theoretic discharge, or that which would take place if the whole orifice transmitted fluid with the velocity of a body that had fallen from the surface. It is evident that only those particles which are vertically above the centre of the orifice can descend through it in a straight line. All others coming from the sides of the vessel must move in lines more or less inclined. Hence the particles on the outside of the effluent stream are retarded, and move more slowly than those in its centre. Hence also arises the difference between the *mean velocity* of the escape and the velocity due to gravity.

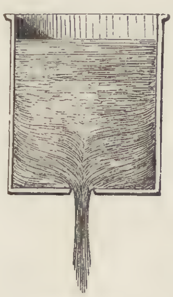


Fig. 1199.

The division of the vein at a certain distance from the orifice is not produced only by the presence of the air; it takes place *in vacuo*, and is the result of the acceleration due to gravity. The effect of this acceleration is best seen in a stream of treacle, which tapers downwards, because the flow, or quantity passing in a given time, must be equal at all points of the stream, so that wherever the *velocity* is greater than at another point, the size, or *sectional area*, of the stream must be diminished in the same proportion. In water, however, the cohesion is not of such a kind as to admit of this tapering; but each portion, when it has acquired a certain velocity, tears itself away from the stream, forming a drop, and leaving the stream, which has been forcibly elongated, to contract again, till another drop is detached. Thus each drop is subject during its fall to certain periodic vibrations, by which it alternately elongates and contracts. A series of pulsations, also, occurs at the orifice, the number of which is in the direct ratio of the rapidity of the current, and in the inverse ratio of the diameter of the orifice; they are often sufficiently rapid to produce a distinct musical sound. If a note in unison with this be played on a musical instrument at such a distance as to be scarcely audible, the aërial pulses thus produced have a marked effect on the vein in shortening the limpid part.

When a tube is added to the orifice, the flow is accelerated if air be present, but, *in vacuo*, no such acceleration takes place. The most remarkable and useful result, however, of the experiments on the flow of water through pipes, is the discovery that it may be accelerated by merely giving particular forms to the commencement and termination of the pipe, without altering its general capacity. A 4-inch pipe, of any length, may be made to deliver considerably more water, if its first 3 inches and last yard be enlarged conically, than if they were cylindrical like the rest of the pipe.

One of the most intricate subjects to which the laws of motion have yet been applied deductively, is that of *liquid waves*. When any portion of a liquid surface is raised above or depressed below the rest, we have already seen, Fig. 1191, that it will return to the general level, but in so doing it acquires a velocity which necessarily carries it beyond the position of equilibrium, and thus produces a series of oscillations, which are communicated in every direction over the liquid surface, each portion receiving its motion from that preceding it, and therefore arriving at each phase of its oscillation a little later than the preceding portion; whence arises the appearance of a form travelling along the surface, which form we call a *wave*. Each wave contains, at any one moment, particles in all possible stages of their oscillation, some rising, some falling, some at the top of their range, some at the bottom; and the distance from any row of particles to the next row that are in precisely the same stage of their oscillation, is called the *breadth of a wave*. Now as these oscillations are caused by the force of gravity, we may expect some analogy between their laws and those of the pendulum; and accordingly, when the depth of the liquid is disregarded, or considered as unlimited, the wave-breadth (like the pendulum-length) varies as the square of the time of oscillation; so that the time which elapses between the arrival of the crests of two successive waves at a fixed point, is as the square root of the distance between them, or the distance which either of them travels over in the said time; hence it is easy to see that their velocity varies inversely as the square root of their breadth. For instance, if a certain buoy be observed to rise and fall twice as often as another, the waves which pass it must be four times as broad as those which pass the other, but as they travel over this *quadruple* distance in only *double* the time, they must evidently move with a double velocity.[1] When the water, however, is so

(1) The velocity of waves that run in the same or the opposite direction with a ship, may be ascertained by means of the log, or any other floating body, attached to a known length of cord. By noticing the time that elapses between the lifting of this body, and that of the ship's stern, by the same wave, and adding or subtracting the way made by the ship during that interval, we find the

shallow that the waves are affected by the form of the bottom, the simplicity of these results gives place to an extreme degree of complexity. The use of these investigations lies in their application to the *tides*, which may be regarded as waves of moderate height, but enormous breadth and velocity, the time of oscillation being half a lunar day, and the velocity sometimes 1,000 miles an hour.

To Hydrodynamics belongs, also, the theory of such machines for raising water as do not depend on atmospheric pressure. Such are the *water-screw*, invented by Archimedes, the endless *chain of buckets*, the *water-ram*, the *hydraulic belt*, &c. This last-named machine, the use of which has been revived within a few years, is one of the most efficient of water elevators, yet the most inexplicable in its action. In its ancient form it consisted of a number of hair-ropes, for which a band of flannel, or felt, is now substituted, passing over two rollers, one at the top, and the other at the bottom of the well. By means of the upper roller, it is set in very rapid motion, when the water adheres to its surface in a layer which is thicker the more rapidly it moves, and becomes nearly half an inch thick when the velocity is 1,000 feet per minute. It follows the band to any height, and is thrown off by centrifugal force, in turning over the upper roller.

To this science also belongs the application of the power of streams and waterfalls to useful purposes. The chief means of effecting this, are, the *undershot* wheel, the *overshot* wheel, the *breast* wheel, the *horizontal* water-wheel, the *hydraulic engine*, *Barker's mill*, and the *Turbine*. The first two are too well known to require a description, but we may observe, that the overshot wheel is always the most advantageous where the height of the fall is sufficient to admit of its use. The smallest rill may be applied in this manner, but the undershot wheel requires a considerable body of water. The breast wheel unites, in some measure, the advantages of both, and is applicable to falls of a medium height, as it requires only a fall equal to its *radius*, and not to its *diameter*, as is the case with the overshot wheel. This wheel is formed with plain floats, but the water enters at the level of its axle, and descends round one quadrant of its circumference, which is enclosed for this purpose in a sort of box of masonry. The horizontal water-wheel is used in some parts of France, and is the most applicable to a small fall, and a small quantity of water. Its floats are set diagonally, and may receive the water at one or at several points of its circumference at once. In the hydraulic engine, the pressure of a column of water is applied as the motive power, by means of a piston and cylinder, like those of the steam-engine. The Turbine, which acts on a similar principle to that of Barker's mill, may be described as a water-wheel with a vertical axis; it has hitherto been principally used in France, where it has been brought to great perfection. It is, perhaps, the least wasteful of all modes of applying the power of a waterfall. It will be described more particularly further on.

In all water-wheels it is a constant rule that the greatest mechanical effect will be produced when the velocity of the parts driven is just *half* that of the stream driving them; and this is a most important principle, applicable also to the sails of windmills and ships, and the paddles of steamers. It is obvious that the pressure of the wind or water on any of these bodies diminishes as their velocity approaches that of the current, so that if it were possible for a water-wheel to revolve with exactly the velocity of the stream, there would be no pressure on its floats, and consequently, no power to drive any other machinery. On the other hand, the pressure is at a maximum when the wheel is standing still, but then having no velocity, it is also powerless. As the power then is proportional to the *product* of the pressure and velocity, it is greatest when they have each their mean value, that is, in the exact medium between these two states,—*rest* and *motion with the current*,—in other words, it is greatest when the velocity is *half* that of the current.

We will conclude this concise statement of the principles of Hydrostatics and Hydraulics, (for which the Editor is indebted to his small work on Mechanics, published in Weale's Rudimentary Series,) with a detailed description of those very important machines, the *hydrostatic press* and the *hydraulic ram*.

HYDROSTATIC OR HYDRAULIC PRESS.—Although a machine of this kind was proposed by Pascal in 1664, it was not till 1796 that Bramah succeeded in overcoming certain difficulties in its construction, which will be explained presently. One form of the press is represented in Fig. 1200, the working parts

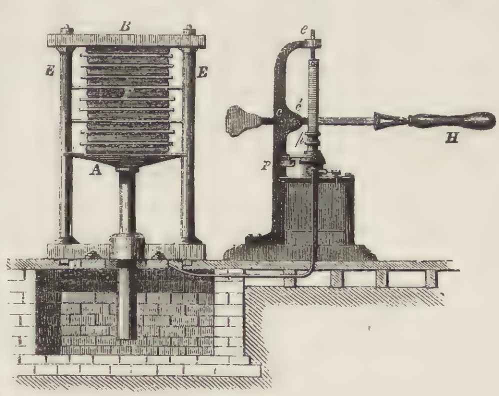


Fig. 1200.

of which are shown in section in Fig. 1201: C is a massive cylinder, in which the solid piston or plunger P moves up and down, carrying at the top a plate A, between which and the top of the press B, the goods or substances F intended to be pressed are

time which the wave takes to travel the length of the cord. In this way it has been found, that in the open ocean, some waves travel at the rate of 80 miles an hour; the breadth of such waves is sometimes a quarter of a mile. The utmost difference of level is found by measuring how high above the ship's water-line an eye must be raised to have an uninterrupted view of the horizon. No authentic observation of this kind gives more than 25 feet, even in the greatest storms.

placed. Water is forced into the cylinder C by means of a pump P, of which the long piston *r* is worked by a lever upon a point *c*, and terminating in a handle H, the piston *r* being further guided in its vertical

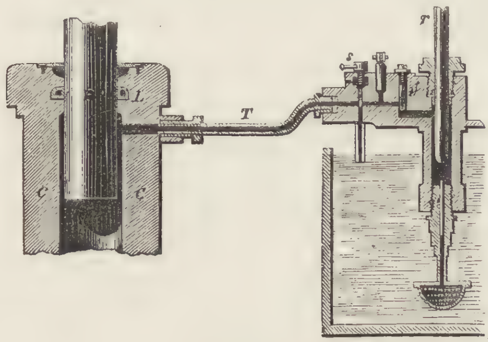


Fig. 1201.

motion by a ring at *e*, in which the stem of the piston *r* works. At each up-stroke of the piston, water is drawn up from a reservoir placed beneath the pump, and at each down-stroke, it is forced along the tube T into the cylinder C. A valve *v* opening upwards allows water to pass up from the reservoir, but not to return back again; and another valve V′ opens to allow the water passage along T into C, but closes against its motion in the contrary direction.

Now it is evident from what has been already said, that the power of this machine depends partly on the proportion of the magnitudes of the two pistons, and partly on the leverage of the arm *c* H. Suppose the diameter of the cylinder to be 12 inches, and that of the piston of the small pump or injector only $\frac{1}{4}$ of an inch, then the proportions between the two surfaces or ends of the pistons, will be as 1 to 2,304, so that a force applied to the small piston will be multiplied 2,304 times. If the small piston or injector be forced down with a pressure equal to 20 cwt., the piston of the great cylinder will act with a force equal to $20 \times 2{,}304 = 46{,}080$ cwt. $= 2{,}304$ tons, which enormous power may be applied either in drawing or pressing in much less time than the same could be produced by any other means.

Now the difficulty in constructing this press before the time of Bramah, arose from the leakage of water from the cylinder C, which, of course, rendered the press useless. Bramah overcame this difficulty by constructing a leathern collar L in such a way, that the very tendency of the water to escape, only caused such collar to fit the more tightly in its place. To make this collar, a circular disc of leather is first cut out; and from this a second disc is removed, so as to leave a broad flat ring. This is softened by steeping in a liquid, and then bent and moulded into a collar of the form shown in section, Fig. 1202, in which condition it is fitted into a circular cavity L,

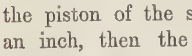


Fig. 1202.

Fig. 1201, made for the purpose in the cylinder C. The plunger P is then put into its place, and it moves up and down with friction against the interior bend of the collar. Now it is evident that when the water is forced into C, it will insinuate itself into the hollow concavity of the collar, and being under an enormous pressure, will press the collar tightly into its place, and thus form a perfectly tight joint.

The power of this press is only limited by the strength of the cylinder C. We have already seen, that in raising one of the tubes of the Britannia Tubular Bridge, the cylinder of one of the enormous hydrostatic presses used for the purpose, gave way. [See BRIDGE, vol. i. p. 248.] It is usual, however, in order to prevent such an accident, to furnish the press with a safety-valve, consisting of a conical plug pressed down by a weighted lever, as shown in Fig. 1203. The size of the weight W, and its distance from the fulcrum are determined, so that the valve shall not yield to the pressure

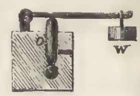


Fig. 1203.

of the liquid, until such pressure exceed a certain limit, at which it is desired to work.

The action of the press can be suspended in a moment by means of the screw *s*, Fig. 1201, the lower part of which plugs up a channel leading into the supply cistern. On turning this screw one way, the water cannot escape, and the water raised by working the pump-handle H, Fig. 1200, is employed as power to raise the plunger P; but on turning the screw the other way, the water flows back into the cistern, the pressure in C is instantly relieved, and P descends.

A press recently patented by Mr. Wilson, exhibits a marked novelty in being constructed with two concentric rams. These are acted upon alike by the water, but from the difference of the areas of the two, the large or outer ram always tends to rise first, carrying of course the smaller ram with it. Such a form of press tends much to economise labour in working substances which may be pressed in a case or cylinder. The arrangement of parts and mode of working, will be best understood by the following description. The two rams A, B, Fig. 1204, are exposed to the same working pressure, there being a hole left in the large ram A, to admit the water to the small interior ram. The check rod C, serves to stop the large ram whenever it has risen to a certain height, while strong bolts fixed on the top of the water cylinder (but not shown in the figure) are placed so as (when pushed in) to prevent the large ram from rising at all. Leathers of the usual form are applied to form water-tight joints around this check rod, and also around both rams. The oil cylinder D D is of stout cast-iron, and is pierced with holes to allow the escape of the oil from the substance submitted to pressure within it. The top or head of the press E is movable, and is, when in its place, kept down by the dogs or hinged catches *f f*, forming the ends of the press bars F F. The mode of using this press is as follows:—The top E, being lifted off by means of a chain and winch, and the pumps set to work, the large ram rises as far as the check rod will allow it, and then the small ram rises alone to near the top of the oil cylinder. The water is then allowed to escape slowly, and as the small ram first, and then the two rams together, sink, the charge is filled into the cylin-

der D D, in the usual portions, divided by iron plates, and mats, or baskets. When the charge is complete, the top is put on, and the large ram being held down by the bolts, a light pressure is given by the small ram, to compress and consolidate the loose charge.

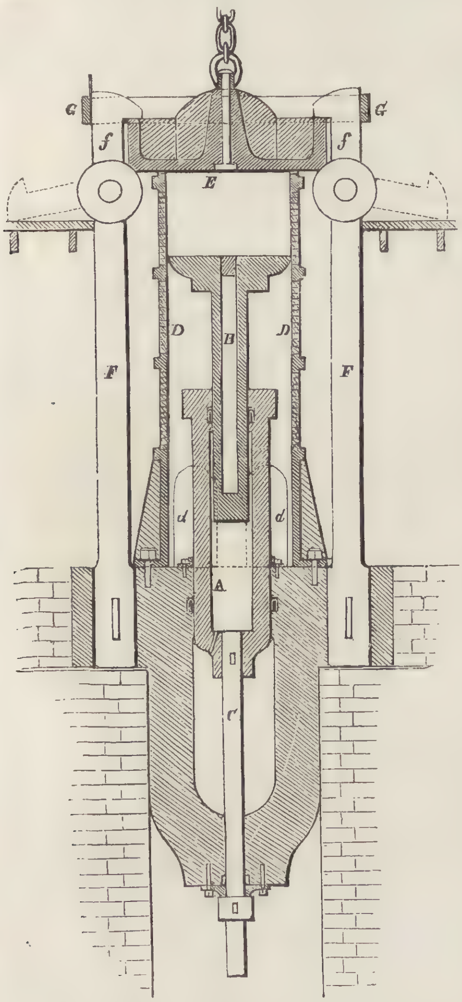


Fig 1204. SECTION OF DOUBLE HYDROSTATIC PRESS.

The head is again removed, and as the water is allowed to escape slowly and the ram to fall, the space left in consequence of this compression is filled or "topped up" by additional charge. Then all being ready, the head is again put on and secured by the dogs, which are prevented from springing back by the ring G G, wedged up behind them, the large ram is released and the full pressure applied and maintained as long as necessary. When this is completed, the pressure is slackened, so as to permit the removal of the head, and the pumps are again put to work, so as to raise at first the two rams, and then the small one alone, and thus lift the spent charge out of the oil cylinder. Then the same process of charging, topping up, and finishing, is gone over again as at first. The advantage in this press arises from the capability of operating upon a large quantity of material in a long cylinder of small area, and therefore under a great pressure, while from the use of the two rams as described, the loose charge is rapidly consolidated by a first pressure quickly applied, and the spent charge, which from the small area of the oil cylinder could not be dug out, is readily lifted out by a slow motion, which allows of its easy removal. For hot-pressing, the oil-cylinder may either be surrounded by a steam-jacket of iron plate, or the entire press may be built into a hot room, leaving only the top of the oil-cylinder open to the charging floor above. The oil which flows down the sides of the oil-cylinder, is collected in a tray placed beneath it, and conducted by a shoot or pipe into the proper vessel or reservoir. The bolts are placed in openings *d d* at the bottom of the oil-cylinder, which openings serve also to give access, when needed, to the leathers of the two rams. For some purposes, the large ram might be left without any hole for the admission of the water to its interior, from the water-cylinder, and a pipe, sliding in a water-tight collar, might be made to convey the water directly from the pumps to the interior of the large ram. This, then, becomes a cylinder to the small ram, and the check rod and bolts may be dispensed with, as the water may be made to act on either of the rams alone, by the adjustment of the cocks in the supply pipes. Care must obviously be taken in all cases, not to apply too great a pressure to the small ram when rising alone, for fear of breaking the bolts or check rod of the large ram, or when separate pipes are used, for fear of bursting the large ram, if it is at all raised out of the cylinder.

THE WATER RAM, or *Belier Hydraulique,* invented by Montgolfier, and improved by his son, is one of the most simple and beautiful of hydraulic machines. Its object is to raise water without the aid of any other force than that produced by the momentum or moving force of a part of the water that is to be raised; and the effect is so great, that the machine appears to act in opposition to the laws of hydrostatic equilibrium, for a moving column of water of small height is made to overcome and move another column much higher than itself.

The construction and action of the water-ram will be understood from the accompanying steel engraving, in which H is a head of water discharging itself into a pipe B, along which it flows with a velocity depending on the height of the fall, and it escapes to waste unless prevented at the orifice C, which admits of being opened or shut by a valve. F is a reservoir of air, which is connected with the conduit tube B D by a small cylinder *a b c d*. In the bottom of F is a circular orifice, to which a small cylindrical support is adapted, of which the extremity E is furnished with a valve. F is supplied with air by a valve *s*, and there is also a space, *m n*, full of air. G A is an ascent tube, rising into a cistern at the top of the house, or to any considerable elevation where a supply of water is required. The pipe B D, through which the water runs, is called the *body of the ram;* the pipe G H, the *tube of ascension;* C is the *stoppage*

valve; and E the *ascension valve.* These valves are hollow globes weighing about double the weight of water which they displace, and over each is a metal bridle to prevent it from rising too high. The extremity of the body C, and the reservoir E, form what is called the *head of the ram.*

The action of the ram is as follows:—The water escaping through C with a velocity due to the height of the fall, forces the ball D out of its muzzle, and raises it to the orifice C, which it immediately stops. The water thus suddenly arrested in its passage, would, by its momentum, burst the tube, were it not for the other valve *e*, which is lifted up, and allows the water to escape into the reservoir F, whereby the air is compressed, and by its spring, forces water up the tube A, just as water is forced out of the jet by the elasticity of the air in the air-chamber of a fire engine. [See FIRES, vol. i. p. 662.] The ball *e* soon loses the velocity imparted to it by the stopping of the orifice C, and descends by its own weight, as does also the ball D, into their first positions; the water then runs off again at C, until its velocity is sufficient to raise the ball D, when the orifice is again closed, and E again opened by the reaction, and thus the effects are constantly repeated, in times which are sensibly equal, in the same ram, and with the same current.

In the action of this machine, four distinct periods may be traced: 1, the water-escapes through the orifice C, with a velocity due to the fall, and that orifice is closed; 2, the air in the space *m n* is compressed; 3, the ascension-valve is opened, the air in the reservoir compressed, the water rises in the ascension-tube G, the ascension-valve *e* is shut, as is also the valve D; 4, the air compressed in the second interval reacts, the valve D descends from the orifice, and the water, again acquiring its velocity, again produces the like effects.

It will be seen from these details, that a very insignificant pressing column *h h'* is capable of raising a very high ascending column G A, so that a sufficient fall of water may be obtained in any running brook by damming up its upper end to produce the reservoir H, and carrying the pipes B D down the channel of the stream until a sufficient fall is obtained. A considerable length of descending pipe is desirable to ensure the action of the machine, otherwise the water, instead of entering the air-vessel, may be thrown back into the reservoir. Air is admitted from time to time into the annular space *m n*, whence it finds its way into F.

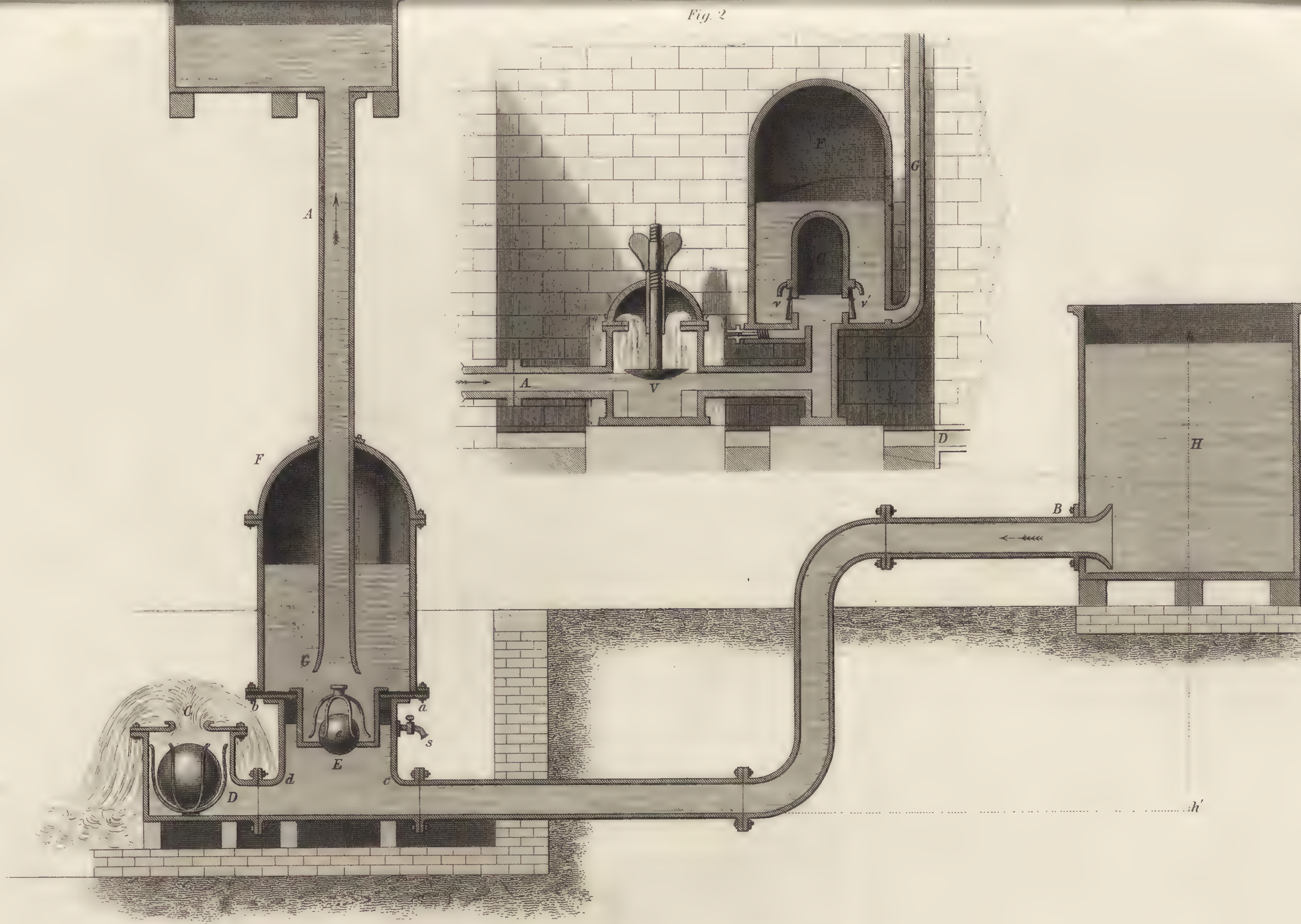
To estimate the value of this or, indeed, of any hydraulic engine, its produce must be ascertained, the expense of its erection, and that of keeping it in repair. In every hydraulic engine, the force expended is the product of the water as it comes from its source, multiplied by the height through which it falls before it acts on the machine; the produce being the quantity of water raised in the same time, multiplied by the height to which it is elevated.

In a ram placed by Montgolfier in his garden, the fall, which was procured artificially, was 7½ feet. The height to which the water was raised, 50 feet; the diameter of the tubes 2 inches; the water expended in 4 minutes, was 315 litres, that elevated 30 litres; hence the expense of force employed is $7\frac{1}{2}\times 315 = 2{,}362$; the useful force $50\times 30 = 1{,}500$, which give the ratio of 100 to 64 as the expense to the produce. It appears, however, from the mean of a number of experiments, that the expense will be to the produce as 100: 57, so that a hydraulic ram executed with care, and placed in not unfavourable circumstances, employs usefully, at least, half its force.

The younger Montgolfier so far improved upon this machine, as to make the work performed amount to about 60 per cent. The alterations introduced by him, are shown in the second figure of the steel engraving, in which A is the feed-pipe or body of the ram; V the stoppage-valve suspended by a stem to a sort of stirrup; F the air reservoir, enclosing a smaller reservoir C, called the *air-matrass; v v'* are the ascension-valves, and G the tube of ascension. The action is as follows:—The water in A flowing in the direction of the arrow, soon acquires sufficient velocity to close the valve V, and to open the valves *v v'*, whereby a certain quantity of water enters F, and passes up G. This impulse or momentum being expended, the valve V descends, the water overflows, and is carried off by a pipe D; after which the same phenomena are repeated. Now it will be seen, that as soon as the water rises above the valves *v v'*, air is imprisoned in the matrass C, and when the force of the water after shutting V comes to expend itself upon the air-vessel F, the violence of the shock, which is considerable in the arrangement shown in the first figure, is in this case greatly lessened by the interposition of C, which acts as a sort of air-cushion; it also causes the valves to shut with less noise, and prevents the pipe from undergoing such violent strains. In short, while a much larger amount of work is done, all the operations take place with so much ease, that the machine is less shaken and put out of repair than in the former apparatus. When the force which opens the valves *v v'*, and compresses the air in C is expended, this air expands, and in doing so, assists the retrograde motion of the water in the pipe. The air in C, in expanding, has for a moment a less pressure than the external air, a circumstance which is turned to use ful account in keeping both C and F supplied with air, as will be noticed presently. The valves *v v'* remain open so long as the opening pressure exceeds that which is exerted upon them by the fluids in F. The air-vessel F also derives advantage from the matrass C, for as soon as the valves *v v'* are opened, and water enters, compressing the air in F, the water is not immediately forced up the tube G, but can accumulate somewhat in F, and thus act with great effect, for it is evident that the pressure required to open the ascension-valves, would be much greater if the whole column of water G passed suddenly from a state of rest into one of motion at the moment the valves were opened, and they would in such case also remain open a much shorter time.

One of the great defects of the fire-engine, is the

Fig. 2



HYDRAULIC RAM

absorption of the air in the air-chamber by the water, which takes place all the more rapidly as the pressure is great. Now the air in F becomes dissolved rapidly in proportion to the increasing elevation of water in the ascension-tube: wherefore in order to keep up a constant supply, a small snifting-valve is added at H, consisting merely of a tube with a fine capillary bore left entirely open. At the moment when the water of the ram is relieved from pressure, the density of the air in C becomes slightly less than that of the outer air, as already noticed; consequently a small portion of air rushes in through the valve with a noise like the *sniffling* of a person's nose, whence this kind of valve is called a *snifting*-valve. A portion of the air thus admitted finds its way through the valve v v' into F, to supply the place of that which is dissolved, and carried off by the ascending-column. At every blow of the ram, *i. e.* every time the valve B is closed, and the water is under compression, a small jet of water is darted out of the snifting-valve; this valve therefore acts as a sort of pulse to the machine, drawing in air and jetting out water by regular periodical movements. Indeed the pulsatory motion of the ram becomes painfully evident where the column to be raised is considerable. In such case, the ground over the pipe is shaken at every blow, and a tremor is felt in every room of the house against the wall of which the supply-pipe ascends. By covering this pipe with felt, the evil may be to a certain extent mitigated, but cannot be entirely overcome. Indeed this is the great objection to this otherwise admirable engine.

In the Great Exhibition, a hydraulic ram was exhibited in action by Messrs. Easton & Amos. They have also one in action in the yard of their premises in Castle Street, Trafalgar Square. They state in their circular, that they have erected upwards of 500 of these machines in different parts of Great Britain and Ireland. Persons who have small running streams on their estates, and require water to be raised to the tops of their houses, can do so at very moderate cost. These self-acting water-rams will raise water 30 times the height of the waterfall by which they are worked. In giving estimates, the makers require to know:— 1. The number of feet fall that can be obtained at the spring or brook to work the ram. 2. The perpendicular height from the lower part of the fall to where the water is required to be delivered. 3. The distance horizontally from the spring or brook to the house or premises where the water is wanted. If the spring or stream should be small, it is desirable to ascertain how many gallons flow per minute.

The *Turbine*, or *horizontal water-wheel*, is practically unknown in Great Britain, although in extensive use in France and Germany, and its working results are so extraordinary, that some account of it may be of use in this place.

In order to understand the principle of the turbine, we must refer more particularly to Dr. Barker's mill, shown in plan and elevation, Figs. 1205, 1206. It consists of an upright pipe or tube, with a funnel-shaped open top, but closed at the lower end, from which project two horizontal pipes or arms, closed at the outer ends and placed opposite to each other at right angles with the vertical tube. Near the end of each horizontal pipe, and on one side of it, is a round hole, the two holes being opposite to each

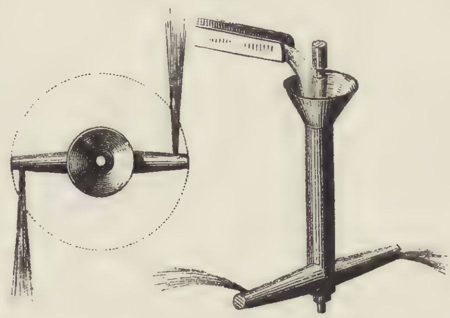


Fig. 1205 *Fig.* 1206.

other. The upright pipe is mounted upon an axis or spindle, and is kept full of water, which flows into the top. The water issuing from the holes on opposite sides of the horizontal arms, causes the machine to revolve rapidly on its axis, with a velocity nearly equal to that of the affluent water, and with a force proportionate to the hydrostatic pressure given by the vertical column, and to the area of the apertures: for there is no solid surface at the hole on which the lateral pressure can be exerted, while it acts with its full force on the opposite side of the arm. This unbalanced pressure is, according to Robison, equal to the weight of a column, having the orifice for its base, and twice the depth under the surface of the water in the trunk for its height. This measure of the height may appear extraordinary, because if the orifice were shut, the pressure on it is the weight of a column reaching from the surface. But when it is open, the water issues with nearly the velocity acquired by falling from the surface, and the quantity of motion produced, is that of a column of twice this length moving with this velocity. This is actually produced by the pressure of the fluid, and must therefore be accompanied by an equal reaction. When the machine, constructed as in Fig. 1206, moves round, the water which issues descends in the vertical trunk, and then moving along the horizontal arms partakes of the circular motion. This excites a centrifugal force, which is exerted against the ends of the arms by the intervention of the fluid. The whole fluid is subjected to this pressure, increasing for every section across the arm in the proportion of its distance from the axis; and every particle is pressed with the accumulated centrifugal forces of all the sections that are nearer to the axis: every section, therefore, sustains an actual pressure proportional to the square of its distance from the axis. This increases the velocity of efflux, and this increases the velocity of revolution; which mutual co-operation would seem to terminate in an infinite velocity of both motions. But on the other hand, this circular motion must be given anew to every particle of water as it enters the horizontal

arm. This can only be done by the motion already in the arm, and at its expense. Thus there must be a velocity which cannot be overpassed, even by an unloaded machine. But it is also plain, that by making the horizontal arms very capacious, the motion of the water to the jet may be made very slow, and much of this diminution of circular motion prevented.

Desaguliers, Euler, John Bernoulli, and De la Cour, have treated of this machine, and a few years ago Mr. James Whitelaw, of Paisley, took out a patent for improvements in it; but the turbine, as used in France, appears to be the invention of M. Fourneyron, and its value consists in its applicability to falls of water so high or so low that an ordinary water-wheel cannot be used; and in falls of great height it requires little or no mill work to produce the requisite speed.

The turbine in its present form consists of a horizontal water-wheel, in the centre of which the water enters; diverging from the centre in every direction, it enters a number of buckets at once, and escapes at the circumference or external periphery of the wheel. The water acts on the buckets of the revolving-wheel, with a pressure proportional to the vertical column or height of the fall: and it is led or directed into these buckets by stationary guide curves, placed upon and secured to a fixed platform within the circle of the revolving part of the machine. The efflux of the water is regulated by a hollow cylindrical sluice, to which a number of stops, acting

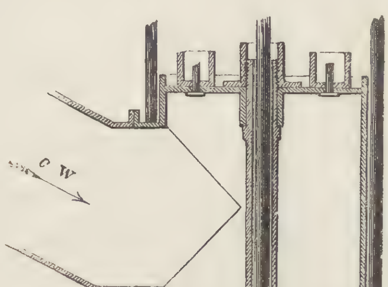


Fig. 1207. SECTIONAL ELEVATION OF TURBINE.

simultaneously between the guide curves, are fixed. With this short cylinder or hoop they are all raised or lowered together, by means of screws communicating with a regulator or governor, so that the opening of the sluice and stops may be increased or diminished in proportion as the velocity of the wheel may require to be accelerated or retarded. This cylindrical sluice alone might serve to regulate the efflux of the water, but the stops serve to steady and support the guide curves, and prevent tremor.

Fig. 1207 is a section of the turbine, erected in 1837 at St. Blasier, in the Black Forest of Baden, and Fig. 1208 a quadrant of the same. The body of the machine is of cast-iron; the water-wheel or revolving part, is of hammered iron, and the spindle or axis E, of steel; B is the cylindrical sluice or regulator;

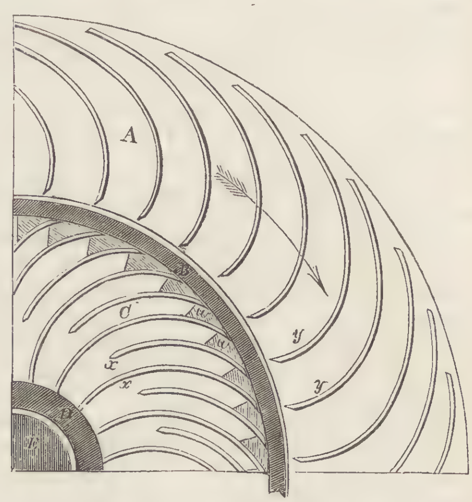


Fig. 1208. QUADRANT OF TURBINE.—*Plan.*

w w the stops; C the fixed platform; *x x* the leading or guide curves which conduct and direct the water into the buckets *y y;* D is the hollow shaft supporting the platform C. The axis of the water-wheel E makes from 2,200 to 2,300 revolutions per minute, and drives the machinery of a cotton mill. The arrow shows the direction of rotation. The foot of the spindle, and the pivot and step on which it revolves, are tempered to extreme hardness. The oil pipe at the foot of the pivot is connected with a small force-pump or syringe, which, at regular intervals, injects a little oil into the step for lubrication; the pump is worked by a slow motion from the machinery. The foot of the spindle must be made hollow, and run upon a fixed pivot. The spindle must never run in a hollow step. The pivot should be quite cylindrical, and should truly fit the spindle with as little play as possible; the top of the pivot should be but slightly convex. Water and mud must be carefully excluded, and the parts regularly oiled.

This turbine is moved by a fall or column of water of 72 feet. The wheel is of cast-iron, with wrought-iron buckets; it is about 20 inches in diameter, and weighs about 105 lbs.; it is said to be equal to 56 horses' power, and to give a useful effect equal to 70 or 75 per cent. of the water power employed. It is used for driving a spinning mill. A second turbine at the same mill is worked by a column of water 354 feet high, which is brought into the machine by cast-iron pipes of $16\frac{1}{2}$ inches diameter. The diameter of

the water-wheel is about 13 inches, and is said to expend a cubic foot of water per second, or probably more. The width of the water-wheel across the face is less than $\frac{1}{4}$ inch. It makes from 2,200 to 2,300 revolutions per minute, and on the end of the spindle or upright shaft of the turbine, is a bevelled pinion of 19 teeth working into 2 wheels on the right and left, each of which has 300 teeth; these give motion to the machinery of the factory, and drive 8,000 water spindles, with roving frames, carding engines, cleansers, and other accessories. The useful effect is reported to be from 80 to 85 per cent. of the theoretical water power. The water is filtered at the reservoir before it enters the conduit pipes, since the apertures of discharge in the water-wheel are so small as to be easily obstructed. The water enters the buckets in the direction of the tangent to the last element of the guide curves, which is a tangent to the first element of the curved buckets. The water ought to press steadily against the curved buckets, entering them without shock or impulse, and quitting them without velocity, in order to obtain the greatest useful effect; otherwise a portion of the power of the water must be wasted or expended without producing useful effect on the wheel.

The general application of the steam-engine as the moving power for machinery, has to a great extent superseded the use of water power in England. But there are many places, especially in hilly districts, where high falls of water occur, or where reservoirs could easily be made, so as to ensure a constant supply, and where the height of the column may compensate for the smallness of its volume. In such situations the high pressure turbine, or that with a lofty column of water, may be applied with advantage for grinding corn, working threshing machines, crushing ore, &c. In other situations, where a great volume of water rolls with but little fall, with a head of only 9 inches, the low-pressure turbine has done good service.

In places where coal is scarce, but water abundant, there is another engine which may, with advantage, take the place of the steam-engine. This is the Reciprocating *Water-pressure Engine*, a description of which we propose to give under the head, WATER POWER, to which we must also refer for other interesting applications of the principles of Hydraulics and Hydrostatics.[1]

HYGROMETER. See EVAPORATION.

HYPOCAUST. See WARMING AND VENTILATION.

ICE. The command of a proper supply of ice or snow for cooling water or other liquids in summer has long been regarded as one of the necessaries of life. And so ancient is the practice, that we even find allusions to it in the Proverbs of Solomon;—"As the cold of snow in the time of harvest, so is a faithful messenger to them that send him; for he refresheth the soul of his masters." xxv. 13.

Referring to other authorities[2] for antiquarian notices on the art of cooling summer drinks and sweetmeats, we propose to give a slight sketch of the modern method of collecting and storing up ice and snow, so as to afford a constant supply for summer; *secondly*, to state the modes which have been adopted for forming ice artifically; and *thirdly*, the methods of obtaining low temperatures by the use of what are called *freezing mixtures*.

The most simple and obvious method of securing a magazine of cold to meet the physical wants of summer, is to collect, during the winter, a store of ice or of snow, and to place it under such circumstances that it shall be shielded from rain, from warm air, and from the direct rays of the sun.

In our article on the preservation of FOOD, we stated how desirable an appendage to markets, &c., would be an ice-house, for the purpose of preserving fish, meat, fruit, and vegetables fresh much longer than can be done by other means. The simplest method of keeping ice is by enveloping it in a large quantity of loose straw. For this purpose, the ground is formed into a flattened cone, for draining off the water from any portion of the melted ice; a layer of faggots is then put therein, with straw a foot or more in thickness, and on this the ice is piled in a large conical mass, and covered with straw to the thickness of one foot, then with faggot-wood to the thickness of two feet, for the purpose of preserving a stratum of air above and around the ice; and lastly, the whole is covered with two or three feet of straw arranged as a thatch. The ice, thus surrounded with badly conducting materials, may be kept throughout the year. Some recommend as the best situation for such an ice-stack, the shade of trees, or under a shed roof, closed on the south side, and open on the north. Others consider the vicinity of trees to be objectionable, in consequence of their tendency to increase or prolong the humidity of the air. So, also, others recommend an eastern or south-eastern aspect in preference to a northern aspect for the ice-house door, in order that the morning sun may dissipate moisture from it.

An underground ice-house may consist of a large cellar, with the walls, floor, roof, and doors hollow, or double, and with a trapped drain to allow water to escape without admitting the air. Such ice-houses are usually in the shape of an inverted cone, which allows the ice to form into compact masses, in which condition it retains the solid form far better than when it is loosely piled, and should any of the ice thaw out, the slipping down of the remainder will tend to keep the mass together. But the construction of such an ice-house as this, is very costly; and according to

(1) The above notice of the Turbine, is from a report made by Joseph Glynn, F.R.S. &c. to the British Association for the Advancement of Science. Fourneyron's Turbine has been improved and varied by M. Callon, by M. Fontaine of Chartres, by M. Jonval, and by M. M. Kœchlin of Mulhausen. These are described in Delaunay's beautiful little work, entitled, "Cours Elémentaire de Mécanique," Paris, 1851.

(2) The various methods of cooling liquors as practised by the nations of antiquity and traced to comparatively modern times are given by Beckmann in an amusing paper in his History of Inventions. See also Professor Leslie's Treatise on Cold; published in the Encyclopædia Britannica.

Loudon,[1] is not necessary, for "a plain square room with double side walls, say a foot apart, a double arch over, and a double floor under, which can be built with the same ease as any common cellar, will, all other circumstances being alike favourable, keep the ice as long as any conical form whatever." It is desirable to interpose a layer of straw, reeds, or chaff between the walls and the ice; and by a proper arrangement of straw and faggots, an ordinary cellar, if dry, and well situated, will serve as an ice-house. In some places, caverns in limestone rocks, or excavations with a long circuitous passage, by way of approach, may be used for storing ice.

The only communication between the interior of an ice-house and the external air should be by means of the entrance passage, which may be two or three yards long, and be furnished with three or four doors, only one of which must be left open at once. A portion of the passage may be fitted up with shelves, to serve as a pantry, in which case, four doors are necessary, and the space between the first or outer and the second door, and the space also between the second and third doors, should be filled up with straw, which may be conveniently packed up in large bags, or cushions, and suspended from the ceiling. Barley-straw is the best, on account of its being very flexible. The space between the third and fourth doors forms the pantry, the temperature of which may be reduced by occasionally leaving the fourth or innermost door open for a short time. In some cases, the body of the ice-house is fitted with shelves as a pantry.

The form of ice-house usually adopted in this country, frequently fails in keeping the ice, from not having double walls and double or treble doors, or from imperfect drainage.

Fig. 1209 is the ground-plan, and Fig. 1210 the section of an ice-house of approved construction. Loudon says that it will keep ice throughout the year in any climate, if covered with a sufficient thickness of earth or straw. *a* is the well or cellar for the

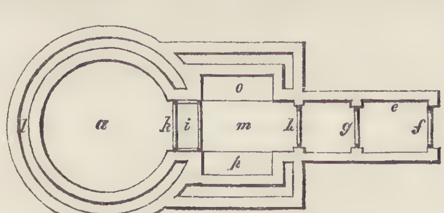


Fig. 1209.

ice; *b* a drain for carrying off the thaw-water; *c* a trap in this drain, to prevent the external air from communicating with that of the ice-house; and *d* a lead pipe from this trap, connected with a pump at *e*, for pumping up the ice-cold water, for the purpose of cooling wines, or after filtration for drinking. There are five doors to this ice-house, at *f*, *g*, *h*, *i*, *k*; and a vacant space *l*, one foot wide, between the two walls surrounding the cellar, and covering the inner division of the passage *m*. This passage *m* may be used as a pantry, as already noticed. The natural level of the ground is shown at *n n*; and the whole superstructure may be covered in Britain to the depth of two or three feet with earth, planted with ivy, and surrounded with trees.

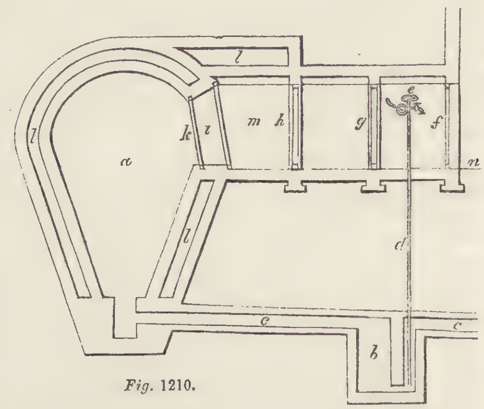


Fig. 1210.

In warmer climates the depth of earth ought to be eight or ten feet. The size of the well ought also to be increased, and a third vacant space round it might be desirable. The space between the door *i* and *k* should be filled up by a barley-straw cushion, and it is desirable to have similar cushions against the doors *g* and *h*, at least during summer. The two recesses *o* and *p* may be increased at pleasure.

In filling an ice-house, the ice should be broken with mallets or stampers to a coarse powder, and well rammed down in the well or pit, keeping the upper surface concave, and adding a little water from time to time, in order to fill up the interstices, and assist the congelation of the whole into a solid mass. It is even recommended to sprinkle the ice with salt water (1 lb. of salt to every gallon of water) from a common watering-pot, at intervals of two feet from the bottom to the top of the mass, an extra quantity being poured on when the filling is completed. The freezing mixture, formed by 1 part salt, and 2 parts pounded ice, will sink a thermometer from the ordinary temperature of a room to 5°; a degree of cold somewhat approaching this being produced in the ice-well, the ice is so firmly compacted together, as to require a pickaxe to break it up the following summer, and the salted ice, according to Loudon, will keep three times as long when exposed to the air as fresh ice.

Snow is preserved in some places in a similar manner to ice, by being rammed down in pits, and well protected from the air at the surface. At Naples, and in the south of Italy, even the poorest persons are accustomed, during the heats of summer, to cool their drink with snow, which is collected from the Apennines, and stored in pits dug chiefly on the northern side of the mountains. The snow is thrown into these pits in broad thick layers, and well pressed together until a considerable mass is collected; the opening is then filled up with branches of trees, dried leaves, or straw; and in some cases, a

(1) Encyclopædia of Cottage, Farm, and Villa Architecture.

rude stone building is erected over it. A few of the loftiest summits of the Apennines rise above the snow-line, and are therefore covered with snow all the year round; but from the lower ridges, the snow melts away in summer, and it is only by making a careful provision at the proper season, that a supply is kept up during the summer. The lower down the mountain the snow-cave is, the less trouble in getting it at the season when it is most wanted, but the greater the risk of its melting away. The situation for the pit must therefore be carefully selected, and the spot be well shaded by trees, or by some projecting portion of rock, to keep off the rays of the sun. On some rare occasions, a snow-shower of considerable thickness will fall during winter on the lower inhabited ridges. An occurrence of this kind produces general rejoicing, for it saves the labour of collecting snow from the heights. Men, women, and children, rush out with shovels, baskets, &c., to gather in their snow-harvest. Immense snow-balls are made, and carefully rolled by the children to the caves. The snow-harvest during winter gives employment to numbers of the peasantry; and the conveyance and sale of the same substance in summer is also a source of constant activity. The task of conveying snow from the mountain caves and distributing it in the various shops of Naples which sell that article only, is performed during the night: mules are loaded with the snow at the mouth of the caves, and they convey it down the mountains to the boats, which take it into Naples; there it is deposited in a large cool building, called "La Dogana della neve;" or, the snow custom-house, where retail dealers come from all parts of the town, to get their supply. The snow-trade is in the hands of government, and produces a considerable revenue. The dealers are bound to sell the snow at a fixed price, and are fined if they do not have a sufficient supply. The snow-shops, of which there is one in nearly every street in Naples, are kept open day and night during the season. Snow is also collected in a somewhat similar manner in Sicily, where the great store-house of snow is Mount Etna.

Of late years, ice has become an article of commerce between countries where it is found in abundance, and those where it is found scantily or not at all. The place where this remarkable traffic commenced, is Wenham Lake, about 18 miles from Boston, in the United States of America; and subsequently, some of the Norwegian lakes have furnished abundant supplies. The Wenham Lake Company was formed, and we learn from the *Illustrated London News* some particulars respecting their proceedings. In September, 1833, a cargo of ice shipped at Boston, was discharged at Calcutta, and sold at 3*d.* per lb. while the native ice cost 6*d.* It was packed in large cubes, fitting closely together so as to form one solid mass, within chambers of double planking with a layer of well-dried refuse tan or bark between them. The quantity shipped, was 180 tons, of which about 60 wasted on the voyage, and 20 on the passage up the river to Calcutta. Thousands of tons are now annually shipped from Boston to our East Indies, to the West Indian Archipelago, and to the continent of South America. The company have erected extensive ice-houses in London, and at Liverpool, and have arranged for importing into this country thousands of tons of ice every year. The masses are so large, that they expose a very small surface to the action of the air, and hence they suffer but very little loss. It is also stated, that ice frozen upon deep water is more hard and solid than ice of the same thickness obtained from shallow water, and melts more slowly. In Great Britain, the collection and storing of ice is very precarious, on account of the uncertainty of the supply during our mild winters; but in America, where the cold of winter is intense, the cutting, storing, and transportation of the ice is regularly carried on throughout the winter.

Wenham lake occupies an elevated position, and lies embosomed in rugged hills. The lake has no outlet, but is fed by the springs which issue from the rocks at its bottom, at a depth of 200 feet. The ice-house, which is capable of storing 20,000 tons of ice, is built of wood, with double walls 2 feet apart all round, the intervening space being filled with saw-dust. The machinery used for cutting the ice is worked by men and horses. From the time when the ice first forms, it is kept free from snow until it is thick enough to be cut; the cutting being commenced when the ice is a foot thick. A surface of some 2 acres is then selected, which, at that thickness, will furnish about 2,000 tons, and a straight line is then drawn through its centre from side to side each way. A small hand-plough is pushed along one of these lines, until the groove is about 3 inches deep and ¼ inch wide, when the marker, Fig. 1211, is

Fig. 1211.

introduced. This implement is drawn by 2 horses, and makes 2 new grooves parallel with the first, 21 inches apart, the gauge remaining in the original groove. The marker is then shifted to the outside groove, and makes 2 more. Having drawn these lines over the whole surface in one direction the same process is repeated in a transverse direction, marking all the ice out into squares of 21 inches. Meanwhile the plough drawn by a single horse follows in these grooves, and cuts the ice to a depth of 6 inches. One entire range of blocks is then sawn out, and the remainder are split off toward the opening thus made with an iron wedge, called an *ice spade*, Fig 1212; when it is dropped into the groove the block splits off with a very slight blow, especially in very cold weather; the labour of *splitting* being slight or otherwise according to the temperature of the air. Low

platforms are placed near the opening made in the ice with iron slides extending into the water, and a man stands on each side of a slide armed with an ice hook, Fig. 1213, with which he catches the ice, and by a sudden jerk throws it up the slide upon the platform. In a cold day everything is quickly covered with ice by the freezing of the water on the platforms, slides, &c., and the huge blocks of ice, some of which weigh more than 2 cwt. each, are hurled along these slippery surfaces with great ease. By the side of the platform is a sled of the same height, capable of containing about 3 tons, which when filled, is drawn over the ice to the front of the store-house, where a large stationary platform of the same height is ready to receive its load, which, as soon as discharged, is hoisted a block at a time into the house.

Fig. 1212.

Fig. 1213.

Forty men, assisted by 12 horses, will cut and stow away 400 tons a day. Sometimes in favourable weather 100 men are employed at once. When a thaw or a fall of rain occurs, the ice is made porous and opaque and unfitted for the market: when snow is followed by rain, and that by frost, the snow-ice thus formed is removed by the *plane*. The operation of planing is somewhat similar to that of cutting. A plane gauge to run in the grooves made by the marker, and which shaves the ice to the depth of 3 inches, is drawn by a horse, until the whole surface of the ice is planed. The chips thus produced are then scraped off, and if the clear ice is not reached the process is repeated. If this makes the ice too thin for cutting, it is left until a few nights of hard frost shall have added below as much as was removed from above.

In addition to filling their ice-houses at the lake and in the large towns, the Company fill a large number of private ice-houses during the winter; all the ice for these purposes being transported by railway.

We come now to the second part of our subject—the production of ice artificially; the most ancient example of which is probably that carried on in the upper country, near the town of Hoogly, about 40 miles from Calcutta. By a skilful application of the process of evaporation the natives are able to procure a supply of ice during their short winter, viz. from the end of November to the middle of February. The ground where the ice is made is a large open plane: 3 or 4 troughs are formed, each about 120 feet in length by 20 feet in width and 2 feet in depth: the bottom is made smooth and allowed to dry by exposure to the sun. It is covered with bundles of rice straw to the depth of about a foot, and then loose straw is strewed in, to within 6 inches of the adjoining land. The water to be frozen is contained in pans of unglazed porous earthenware, very much like those put under our garden flower-pots, and these are arranged in regular order close to each other upon the loose straw in rows to the number of 5 or 6,000. The natives fill the pans with soft water by means of small earthen pots, attached to the end of bamboo-rods, long enough to reach half way across the trough. The water is taken from large water-jars sunk deep in the ground near the pits where the ice is stored, and filled from the neighbouring pools or with drainings from the ice. The quantity of water poured into each pan varies from $\frac{1}{4}$ to $\frac{1}{8}$ of a pint, depending upon the clearness of the sky and the steadiness of the wind. The most favourable wind is from the NN. W.: but any point between N. and W. will do, although less ice is produced. If the wind is between E. and S. no ice will be formed. The ice which begins to appear a little before midnight, is carefully watched by persons stationed near each trough. As soon as a slight film of ice appears, the contents of several pans are mixed together, and the freezing liquid sprinkled over the others. The freezing continues till sunrise, when perhaps as much as half an inch of ice will be found in each pan. In very favourable nights the water is entirely frozen. The ice is generally removed by women, 7 or 8 of whom are appointed to each ice-bed: they use a blunt semicircular knife to scoop out the ice, which they throw together with any unfrozen water into earthen vessels placed near them. When these are full their contents are poured into conical baskets, placed over the large water-jars from which the pans are filled; by which means a supply of cool water is collected for the next night's operations. When the ice has been sufficiently drained, it is deposited in wells near the ice-beds; and at night removed to large circular pits lined with mats, and covered over with a straw shed. The heat of the day, even in the ice-making season, is frequently greater than that of the hottest summer days of England, so that after all precautions, a partial thawing goes on in the pits. The water thus produced is carried off through holes in the bottom of the pits to a deep well, which also serves to supply the pans in the ice-bed: thus throughout the process the cold is economised as much as possible. The ice is conveyed in boats to Calcutta by night. When the weather is coldest it is simply packed in bags; at other times in baskets lined with straw mats, and conveyed to the city before sunrise. During the hot season, when ice is most needed, it is scarcely possible to preserve it in any quantity, and the first heavy fall of rain usually melts all that is left of the last ice-making season.

The principle of evaporation has been commonly applied in all ages to the cooling of liquids. A porous vessel which allows a minute portion of the liquid contained in it to ooze out so as to keep the surface constantly moist, gets rid of this surface moisture by converting it into vapour, which is being constantly discharged from it, and as the heat required for the formation of this vapour is derived from the vessel itself and its contained liquid, the temperature of the latter speedily falls. A bottle of water covered tightly with a cloth kept wet and exposed to the

sun or to the wind, will in a short time fall many degrees below the temperature of the air.

Sir John Leslie carried the principle of evaporation so far as to be able to freeze water in a few minutes by placing it under such circumstances, as to cause it to form vapour rapidly, and then removing the vapour as fast as it was formed. We will first speak of his method of cooling liquids. It is known that unless means be taken for the absorption of the water evaporated from the porous vessels, the air will become so saturated as not to admit of further evaporation, especially in a confined mass of air; and he therefore proposed to place near, and exterior to the vessel containing the liquid, some substance which absorbs moisture with avidity. Dry flannel was found to absorb very well; as also trap rock and compound clays reduced to a coarse powder and dried before a strong fire; parched oatmeal acts with energy as an absorbent, as also does muriate of lime. But it was found that strong sulphuric acid was the most powerful absorbent, continuing for a long time with slowly diminishing force to attract moisture and capable of having its absorbent powers restored by the application of heat. There are, however, so many and such powerful objections to the habitual domestic use of so highly poisonous and corrosive a substance as sulphuric acid, that we can neither recommend it nor hope to see it adopted; but as this plan may be of use in certain manufacturing processes we gave an outline of Sir John Leslie's method. He says:—"To cool water in any climate or state of the atmosphere, we have only therefore to put it into a small porous vessel, presenting on all sides a humid surface, and to suspend this within a close wide cistern, of which the bottom is covered with a layer of sulphuric acid. The broad surface of the acid absorbing the moisture as fast as it diffuses itself through the confined air, keeps that medium constantly at a point of extreme dryness, and thus enables it to support with undiminished vigour the process of evaporation." He recommends the use of a cistern or *refrigerator*, Fig. 1214, of a broad cylindrical form, from 12 to 16 inches in diameter, composed of dense glazed earthenware. This is to be placed in a cellar or other cool place, and charged with sulphuric acid to the depth of about ½ inch. A porous earthen pot being filled up to the lip with water, is set upon a low porcelain stand in the middle of the cistern, to which the lid or cover is then carefully fitted. The cooling is completed in from 3 to 5 hours, when the water should be removed. The production of cold is greater when the refrigerator is large, or when a small pot is used, insomuch that the effect will be diminished one half, if the humid surface should equal that of the acid. The power of the refrigerator is always the greatest at the season when it is most wanted; that is, a given quantity of water on a hot day can be lowered a greater number of degrees than on a cold day.

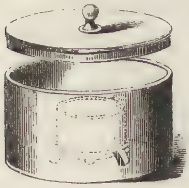


Fig. 1214.

When the thermometer is at 95° in the open air, the refrigerator will reduce the water in the porous vessel to 59°, but when the thermometer is at 50° the water can be cooled to 32°. By supplying a succession of porous earthen pots, the acid will continue to act till it has absorbed half its weight of moisture, during which time it will have assisted in cooling about 50 times that quantity of water exposed to evaporation. Butter may also be kept cool for the table in summer, by putting it after being washed with water into a wet porous pot, and shutting this up for a couple of hours in the refrigeratory. To cool wine sufficiently, one bottle only is used at a time in the smallest refrigeratory. A sheath of stocking or flannel, previously soaked in water, being drawn over the body of the bottle, it is laid in a reclined position on a porcelain slider near the surface of the acid, and left shut up for 3 or 4 hours.

But by the use of the air-pump Leslie showed, in a striking manner, the absorption and disappearance of sensible heat during evaporation. A shallow dish of sulphuric acid was placed on the table of the air-pump, and over this, upon a glass tripod, a metal vessel containing water. On covering this with a receiver, and pumping out the air, the water first discharges the air dissolved in it, and by the rapidity of its evaporation appears to boil. As fast as the vapour is formed it is absorbed by the sulphuric acid, and as the heat necessary to the formation of this vapour is derived from the water itself, the latter quickly loses the heat necessary to its existence in the fluid form, and it becomes solid or freezes. If during this process the bulb of a thermometer be kept in the water, it will be observed that the temperature falls several degrees below the freezing point before congelation takes place; but as soon as it freezes it rises to 32° in consequence of the escape of the residuary latent heat. Leslie proposed this method as a means of procuring ice in hot climates, and suggested for the purpose a large single-barrel air-pump, capable of exhausting 6 or 8 receivers at a time. Attempts have also been made to form ice on this plan on a large scale, by the evaporation of ether contained in a separate vessel under the same receiver with the water, and to pump out the vapour of ether, thus formed, into a separate condenser, so as to be able, for the sake of economy, to use the same ether over and over again. All these plans have failed in practice on account of the comparatively great expense and the small produce of ice.

The production of cold by freezing mixtures depends upon the general law, that in the conversion of a solid into a liquid a quantity of heat, not indicated by, or sensible to the thermometer, is absorbed or disappears, which heat is withdrawn from the surrounding bodies. If the solids be suddenly or rapidly liquefied, the absorption of heat, *i. e.* the production of cold, is very marked. Thus when common salt in fine powder is mixed with snow or pounded ice, these solids suddenly liquefy and run down into brine, which does not freeze till reduced to nearly 0° A mixture of ice and salt is used by confectioners in the

preparation of ices.[1] A mixture of about 3 parts of freshly-gathered, light, flocculent snow, with 2 parts of chloride of calcium, made in earthen vessels previously cooled, will depress the thermometer from 32° to between 40° and 50° below zero, a temperature at which mercury freezes. By the successive application of freezing mixtures in a proper apparatus, Walker succeeded in sinking the spirit thermometer to —91°. Some of the most useful freezing mixtures are given in the following table:—

MIXTURES.	PARTS.	THERMOM. SINKS.	
Sal Ammoniac	5	from 50°	to 10°
Nitre	5		
Water	16		
Nitrate of Ammonia	1	,, 50°	,, 4°
Water	1		
Sulphate of Soda	5	,, 50°	,, 3°
Dilute Sulphuric Acid	4		
Snow	1	,, 32°	,, 0°
Common Salt	1		
Muriate of Lime	3	,, 32°	,, —50°
Snow	2		
Snow	2	,, —10°	,, —56°
Dilute Sulphuric Acid	1		
Dilute Nitric Acid	1		
Snow, or Pounded Ice	12	,, 18°	,, —25°
Common Salt	5		
Nitrate of Ammonia	5		
Snow	1	,, —40°	,, —73°
Muriate of Lime	3		
Dilute Sulphuric Acid	10	,, —68°	,, —91°
Snow	8		

Ice and salt furnish the cheapest and most convenient freezing mixture; but where ice cannot be procured the salts mentioned in the first two recipes given above may be used, and the salts recovered by evaporation when they have served their purpose, so that they can be used over again. "In employing them to cool a bottle of wine, a vessel should be selected a little larger and nearly as tall as the bottle: this vessel should then be filled with the coldest water that can be procured, and the bottle placed in it: about 4 ounces of the salt in fine powder should be sprinkled upon the shoulder of the bottle, so as, gradually dissolving, to fall or run down its sides; as the salt dissolves, the bottle should be gently turned in the mixture, and kept in it till an immersed thermometer tells us that the temperature is rising, which will be in 20 minutes or half an hour." (*Brande.*) A convenient process for freezing a little water, without the use of ice, is to drench finely-powdered crystals of sulphate of soda with the undiluted hydrochloric acid of the shops. The salt dissolves to a greater extent in this acid than in water, and the temperature may sink from 50° to 0°. The vessel in which the mixture is made becomes covered with hoar-frost, and water in a tube immersed in the mixture is speedily frozen. (*Graham.*)

(1) The cream, or other liquid to be frozen, is contained in a thin metallic pan in the cold brine produced by the melting of the ice. Mr. Masters, the confectioner, in his *Ice-Book*, published in 1844, states, that unless the ingredients of the ice be kept in constant agitation during its formation, the watery portions freeze out and separate from the richer saccharine matters, and a badly formed ice is the consequence. To prevent this he has invented a kind of churn, which keeps the ingredients in a constant state of agitation during the congelation.

ICELAND MOSS. *Lichen islandicus.* A lichen, growing freely on the mountains of Scotland, and occasionally employed in invalid diet, to form a jelly which possesses certain tonic and nutritive properties. In the sterile island whose name it bears it is however an important article of food, as a substitute for wheat-flour. It is washed, dried in the sun, and reduced to powder, by stamping in strong bags, after which it only requires sifting to make it applicable to the ordinary purposes of meal or flour. The plant consists of upright leaves, of the peculiar membranous texture common to lichens: these are soft and pliant when moist, but rigid and brittle when dry. The organs of fructification are sprinkled over the exterior surface like small black warts, and the edges of the leaves are fringed with short hairs. The whole plant is smooth and shiny, and inclines to a reddish hue towards the roots.

ICELAND SPAR. Transparent crystalline calc spar, first brought from Iceland. It shows double refraction well.

IGNITION, (from *ignis,* fire,) a property which bodies possess of giving out light whenever their temperatures are raised up to a certain point. The term *incandescence,* (from *incandesco,* to grow very hot,) is generally applied to bodies at a high temperature, which emit light without flame.

ILLUMINATION, ARTIFICIAL. See CANDLE —LAMP—GAS-LIGHTING.

IMPACT, (from *in* and *pango,* to strike,) the meeting of bodies which are in motion, whereby such motion is modified or destroyed. The subject is one of great interest in scientific mechanics. The principal laws of impact are; 1. The common velocity of two non-elastic bodies after impact, when they both move the same way is found by dividing the sum of the products of each body into its respective velocity, by the sum of the bodies; 2. When the bodies meet each other, divide the difference of the products of each mass into its velocity, by the sum of the bodies, for the common velocity after impact. The important law that the angle of incidence is equal to the angle of reflection can also be proved by impact.

IMPENETRABILITY. The two necessary and essential properties of all matter are *extent* or *volume,* and *impenetrability.* It is impossible to form any conception of matter without allowing it some extent, for the smallest conceivable speck must have length, breadth, and thickness; and must therefore occupy a space into which a second speck cannot possibly enter until the first has moved away: this is all that is meant by the impenetrability of matter.

There are however certain cases of apparent penetration of matter: thus, salt may be dissolved in water without increasing the bulk of the fluid, a fact which can only be accounted for on the assumption that the matter of the fluid has interstices or pores, and that the particles of the solid accommodate themselves therein as sand would do if mixed with bullets.

IMPULSE. Any cause by virtue of which velocity is suddenly communicated to a body.

INCANDESCENCE. See IGNITION.

INCIDENCE, Angle of. See HEAT, Fig. 1136.

INCLINED PLANE. See MECHANICS.

INDIAN INK. See INK.

INDIAN RUBBER. See CAOUTCHOUC.

INDIGO. This valuable dye is obtained from tropical plants growing wild, and also cultivated for dyeing purposes, in Asia and America. In the 13th century, Marco Polo found the manufacture of indigo extensive in India, and gave descriptions of the plants which yield the dye, and their mode of treatment, but his accounts were little known or believed, so that long after the dye had been obtained direct from India, under the name of *indicum*, the most erroneous notions prevailed as to its real nature. At Halberstadt, in Germany, it was sought for as a *mineral*, and was included by name in the letters patent granted to some proprietors of mines for the erection of their works.

The product is obtained from numerous species of the genera *Indigofera*, *Isatis*, and *Nerium*, but principally the first named. Thus the *Indigofera tinctoria* of Bengal, Malabar, &c. yields large quantities of the dye, though not of the best quality: a finer kind is the product of *I. disperma*, growing in the East, and also in America, where it yields the Guatemala-indigo: *I. anil*, and *I. argentea*, are other species yielding good indigo, the latter being found also in Africa: *I. glauca* is the species common to Egypt and Arabia: while *I. pseudo-tinctoria*, which is the best of all, is cultivated in the East Indies. *Indigofera tinctoria*, as propagated in the West Indies, is described as having a root about a quarter of an inch thick, and more than a foot long, having a faint smell resembling parsley. From this root issues a short bushy stem of about the same thickness, hard and woody, not rising more than 2 feet. The leaves are winged, or consist of several pairs of leaflets, ranged on each side a long foot-stalk, and having a terminal leaf at the extremity. For about one-third of its upper extent, also, the stem is laden with spikes of very small flowers, destitute of smell, succeeded by long crooked brown pods, inclosing small yellow seeds. Indigo is called "the child of the sun," as it cannot be successfully cultivated anywhere except within the tropics. The Indigoferæ, in common with other leguminous plants, must be considered as having deleterious qualities, but in this, as in many other examples, they are not sufficiently developed to prove injurious. Some of the indigo plants are used as fodder, just as clover, saintfoin, and other members of the same great natural family are with us. Partly on account of the supposed injurious qualities of indigo, but principally, no doubt, through a jealous apprehension that this dye would supersede the British woad, it was denounced in the time of Elizabeth as a dangerous drug, and an act was passed, which remained in force until the time of Charles II., authorizing searchers to burn both it and logwood in all the dye-houses where they were discovered. The prejudice against indigo, both in England and France, is said to have been maintained by the belief that it was a fugitive colour, and injurious to the quality of the wool. After a time, however, when indigo began to reach this country from America as well as Asia, and when the French also brought indigo from the African coast, it gradually took its place among the best dyes, and has now long been recognised as one of extreme value, for which no worthy substitute can be found.

In the eastern mode of cultivating indigo, the seed is sown in March and April, in a light but rich soil, at the rate of twelve pounds of seed to the acre, and the growth of the young plants is so rapid that in June or July they have arrived at maturity, denoted by the expansion of the blossoms, at which time the dyeing principle is most abundant. The first cropping of the plants then takes place, but a second, third, and even a fourth may follow in the same season. The colouring matter is obtained from the whole plant, either by fermentation of the fresh leaves and stems, or by maceration of the dried plant. In the former case the fresh plants, as they are cut off and brought in from the field, are placed in a large stone cistern, which is filled with them to within a few inches of the brim. In order that they may not swell and rise out of the vat during fermentation, beams of wood are laid on them and braced down with twigs of bamboo. Active fermentation soon commences, and is revealed by the frothy bubbles rising to the surface, at first white, then grey-blue, and at last deep purple, when a copper coloured scum also spreads around. The fermentation is now at its height, and the liquor agitated: when it begins to subside the liquor is drawn off into a lower cistern, where it exhibits a glistening yellow colour, changing to green. Several men are then employed in beating the liquor with oars or shovels, while others take off the bamboos and clear out the upper vat of the waste material, (which is dried for fuel,) and prepare it for a fresh charge. The beating of the liquor is continued for an hour and a half; and by its means a great quantity of carbonic acid is disengaged, and the particles of indigo get thoroughly exposed to the atmosphere, and obtain their requisite supply of oxygen; after which they agglomerate in flocks or granulations, the whole assumes the colour of Madeira wine, and on the cessation of the beating, the indigo gradually subsides, leaving the liquor transparent. When the grain is precipitated, the clear liquor is drawn off and allowed to run to waste in some spot where it will not mingle with a brook or pond frequented by cattle, (on account of its deleterious qualities.) A labourer then enters the vat, sweeps up the thick and pulpy matter, and discharges it into a cistern alongside of a large boiler, into which it is passed through a strainer, and heated to ebullition. By this process it is enriched in colour, and increased in weight. From the boiler the mixture is run into a receiver called the *dripping vat*, which has a false bottom of woollen web, through which the liquor filters. As long as it passes through turbid, it is pumped back again into the receiver, but when it runs clear, it is allowed to drain through slowly. The day following, all the drained indigo is put into a strong bag and squeezed in a press. It is then taken out, cut into cubes with a brass wire, and

placed upon wicker-work shelves to dry. A whitish efflorescence soon covers the pieces. This is brushed off; but in some places the cakes are fermented by placing them in heaps in a cask until moisture exudes, after which they are finally covered with a white meal. Five or six days' drying completes the process, and fits them to be packed for exportation.

When the dried plant is used instead of the fresh, (and this is said to be the better method,) the indigo croppings are spread in the sun, like hay, and when dried, are stored in magazines till a sufficient quantity be collected for the purposes of the manufacture. The dried plants are infused in the steeping vat with six times their bulk of water, and are allowed to macerate for two hours with continual stirring till all the floating leaves sink. The fine green liquor is then drawn off into the second vat, and beaten as before. Hot water is sometimes used for macerating the plant, but this does not appear to be necessary.

In the year ending January 1851, 70,482 cwt. of indigo were imported: it pays no duty. The indigo, as imported in cubic cakes, is friable, more or less brittle, and of various shades of peculiar deep blue. When rubbed with a hard body it exhibits a copper-red appearance. The best indigo is so light that it will swim upon water. Its quality depends upon the species of plant, the soil and climate in which it was grown, and the details of the manufacture. The proportion of pure indigo (*indigo blue*) contained in different samples, has not been found to average more than 50 per cent. Crude indigo may be roughly analysed by subjecting it to the successive action of boiling water, alcohol and weak solutions of hydrochloric acid. 100 parts of Guatemala indigo thus treated by Chevreul afforded as follows:—

To Water	Green matter combined with ammonia Deoxidized indigo Extract Gum	12
To Alcohol	Green matter Resin A trace of indigo	30
To Hydrochloric Acid	Red resin	6
	Carbonate of lime	2
	Oxide of iron Alumina	2
Residue	Silica	3
	Pure indigo	45
		100

Pure indigo ($C_{16}H_5O_2N$), also known by the names *indigo-blue*, and *indigotine*, may be obtained from the indigo of commerce in various ways, both by precipitation and by sublimation. By the latter process Mr. Taylor mixes 1 part indigo with 2 parts plaster of Paris, converts the whole into a paste with water, and spreads it to the thickness of about $\frac{1}{8}$ inch upon an iron plate. This, when quite dry, is heated by a large spirit lamp. The volatilization of the indigo is assisted by the vapour of water disengaged from the gypsum, and the surface of the mass becomes covered with beautiful velvety crystals of pure indigo, which may be easily removed by a thin spatula. If the temperature be too high, the indigo is charred and decomposed. Its subliming point is about 550°: its melting point, its point of volatilization, and that at which it is decomposed, are very near each other. When projected on a hot body it gives off a purple vapour as intense as that of iodine, fuses, boils, and burns with a bright flame, giving off much smoke.

Sublimed indigo blue is in the form of flat needles and four-sided prisms, which, seen at a particular angle, have a peculiar and intense copper colour: when lying in heaps they are of a rich brown. The crystals also occur in broad thin plates, which are of a splendid blue colour by transmitted light.

Indigo-blue is without taste or smell: it is neither basic nor acid: it is perfectly insoluble in water and in ether: boiling alcohol merely dissolves a trace of it. Hot olive oil and oil of turpentine acquire a blue tint from it, but on cooling they deposit the minute portion taken up. It is not affected by dilute acids or alkaline solutions. Vegetable blues usually indicate the presence of acids, by becoming of a red colour: indigo is an exception to this rule, and it is a remarkable fact, that sulphuric acid dissolves it without affecting its colour: 15 parts of concentrated sulphuric acid digested with indigo for 3 days form a deep blue pasty mass, which is entirely soluble in water, and is often used in dyeing. It has been named *sulphindylic* acid, and forms blue salts with alkaline bases. If the quantity of acid used for the solution be insufficient, or sufficient time be not allowed for digestion, on diluting the acid mass, a purple powder is left soluble in a large quantity of pure water. The Nordhausen sulphuric acid answers better for dissolving indigo than ordinary oil of vitriol.

One of the most curious and valuable properties of indigo, is the comparative facility with which it loses its colour, becomes soluble so as to allow it to be used as a dye, and then by exposure to the air it reassumes its blue tint and becomes again insoluble. [See Dyeing.] This change takes place when indigo is brought into contact with certain deoxidizing agents and an alkali, and it is probable that under these circumstances the indigo returns to the state in which it existed in the plant. In preparing his *indigo-vat* the dyer uses 5 parts of powdered indigo, 10 parts of sulphate of iron, 15 parts of hydrate of lime, and 60 parts of water: these are agitated together in a close vessel and then left to stand. The salt of iron in conjunction with an excess of lime reduces the indigo to the soluble state; a yellowish liquid is produced, from which, if oxygen be carefully excluded, the *white* or *deoxidized* indigo is precipitated in a flocculent form by an acid, such as the acetic or hydrochloric. Cloth steeped in the alkaline liquid, and then exposed to the air, acquires a deep and permanent blue tint, by the absorption of oxygen and the deposition of solid insoluble indigo in the substance of the fibre. A mixture of dilute caustic soda and grape sugar may be used instead of the iron, salt, and lime, in the above process; the sugar becomes oxidized to formic acid, and the indigo is reduced.

The white indigo appears to be formed by the

accession of hydrogen. Thus blue insoluble indigo, consists of $C_{16} H_5 NO_2$, and white or reduced indigo of $C_{16} H_6 NO_2$. White indigo may also be regarded as a hydrate, and blue indigo as an oxide of one and the same substance; white indigo being represented by the formula $C^{16} H^5 NO + HO$, and blue indigo by $C_{16} H_5 NO + O$.

Indigo is especially interesting to the chemist, and it has been studied with great assiduity by some of the most distinguished chemists. The subject is treated with tolerable fulness in the 8th vol. of Dumas's Traité de Chimie appliquée aux Arts, and also in Brande's Manual of Chemistry.

INFUSION.—See DECOCTION.

INK is variously composed according to the purposes to which it is to be applied. *Common writing ink* is the pertannate of iron, mixed with a little gallate, held in suspension in water by means of gum or some other viscid substance. The gum also prevents the ink from being too fluid, and also serves to protect the vegetable matter from decomposition. A very good ink may be formed from the following recipe: Take Aleppo galls finely bruised, 6 oz.; crystallized sulphate of iron, 4 oz.: gum arabic, 4 oz.; water, 6 pints. Boil the galls in the water, for about 2 hours, occasionally adding water to supply the loss from evaporation; then add the other ingredients, and keep the whole for two months in a wooden or glass vessel, which is to be occasionally shaken. Then strain the ink into glass bottles, adding a few drops of kreosote to prevent mouldiness.

When the ink has not been kept long enough, and is pale in writing, it becomes black in consequence of the oxygen of the air converting the protogallate and prototannate of iron into pergallate and pertannate; but when writing becomes yellow and indistinct from age, it is from the decay of the vegetable portion of the ink, little more than peroxide of iron being left on the paper. By the careful application of infusion of galls the writing may be rendered blacker and more legible, or by washing the writing with a weak solution of oxalic or hydrochloric acid, and then applying an infusion of galls. When the writing paper has been made from inferior rags, bleached with excess of chlorine, the best ink becomes discoloured. Logwood, sulphate of copper, and other ingredients are occasionally added to ink, but their effect is injurious.

Blue ink has of late years been much in request: the colouring matter is said to be sulphate of indigo and tannogallate of iron; or, according to another recipe, Prussian blue dissolved in water by means of oxalic acid.

Red ink is usually made by boiling about 2 ounces of Brazil wood in a pint of water for a quarter of an hour, and adding a little gum and alum. A superior description of red ink may be formed from an ammoniacal solution of carmine. [See CARMINE.]

The great merit of our common writing ink is the freedom with which it flows from the pen, allowing of rapid writing; and the manner in which it bites into the paper, so as not to be removed by sponging. The great defect is want of durability. Such inks partake rather of the nature of dyes. The writing ink of the ancients, on the contrary, is characterised by great permanency; its basis was finely divided charcoal mixed with some mucilaginous or adhesive fluid. *Indian* or *China ink* is of this character: it is formed of lamp-black and size or animal glue, with the addition of perfumes, not necessary, however, to its use as an ink, and is made up in cakes. It is used in China with a brush both for writing and for painting upon Chinese paper; and it is used in other countries for making drawings in black and white; the different depths of shade being produced by varying the dilution with water. The lamp-black must be exceedingly fine, and the ink be prepared with great care.

The permanent character of carbonaceous inks would recommend them to more general use, if a sufficiently fluid vehicle could be found for them. According to Professor Traill, an acetic solution of gluten, forms an excellent basis of a durable and indelible writing ink. The gluten is obtained as usual by kneading the dough of wheat flour in a stream of water until the starch is completely separated: the gluten should be kept from 24 to 36 hours in water, and then be digested in acetic acid of specific gravity 1·033 to 1·034 in the proportion of 3 parts gluten to 20 of the acid. By means of a gentle heat a greyish white saponaceous fluid is obtained, which will keep for a long time. The colouring matter is from 8 to 12 grains of the best lamp-black, and 2 grains of indigo thoroughly incorporated with each fluid ounce of the vehicle. An agreeable aroma may be imparted to the ink by digesting bruised cloves, pimento or cinnamon in a portion of the original acid. This ink is not adapted for writing on parchment, but may be used on paper with a steel pen, which, however, should be washed after use.

Printer's ink is of two kinds, one for letter-press and the other for copper-plate printing. The former is prepared by boiling linseed or nut-oil in an iron pot: it is kindled and allowed to burn for half-an-hour: the vessel is then closely covered over to extinguish the flame: it is again boiled in order to give it the proper drying character, and it is then mixed with lamp-black for black ink; or vermilion for the finer works in red ink; or the pigment is varied according to the colour. For copper-plate-printer's ink the oil is less boiled, and the carbon used is Frankfort black.

Marking ink, used for marking linen, is a solution of nitrate of silver written with a pen upon the linen previously moistened with an alkaline solution, such as potash or soda. In this operation oxide of silver is precipitated upon and combines with the cloth in a very firm manner. The bottles of indelible marking-ink are prepared by dissolving 2 drachms of pure nitrate of silver and 1 drachm of gum-arabic in 7 drachms of distilled water coloured by a little China ink. The preparatory liquid is made by dissolving 2 ounces of crystallized carbonate of soda and 2 drachms of gum-arabic in 4 ounces of water. A much more convenient marking-ink is that used by the

bleachers, viz. coal-tar, made sufficiently thin with naphtha to write with.

Sympathetic inks are noticed under COBALT. The inks for what are called *Chemical Landscapes*, have lately been increased in number. Acetate of cobalt affords an azure blue; chloride of copper a gamboge yellow; chloride of cobalt an Olympian green, and bromide of copper a fine brown.

INTAGLIO.—See SEAL-ENGRAVING.

INTRADOS and EXTRADOS, the inferior and exterior curves of an arch. See BRIDGE, vol. i. p. 198.

INULINE. See STARCH.

IODINE, an elementary substance (i. 126), was discovered in 1811 by M. Courtois of Paris, a manufacturer of salt-petre, in the mother-liquors of that salt. Its affinity for other substances is so strong that it does not occur in nature in a separate state. It is found combined with potassium and sodium in many mineral waters, and also in a minute proportion in sea-water, from which many marine plants and animals have the power of separating it and accumulating it in their tissues. It is also found in a few minerals.[1] Much of the iodine of commerce is prepared at Glasgow from the kelp of the western coast of Ireland and the western islands of Scotland; and the process for obtaining it has been described by Professor Graham.[2] The sea-weed thrown upon the beach is collected, dried and burned in a shallow pit, in which the ashes accumulate and melt by the heat. The fused mass, broken into lumps, is kelp, which was formerly prepared for the sake of its carbonate of soda, varying from 2 to 5 per cent. The long elastic stems of the *fucus palmatus* are said to afford most of the iodine contained in kelp. The kelp is broken up small, treated with water, the solution filtered and evaporated to a small bulk, the chloride of sodium, carbonate of soda, chloride of potassium, and other salts being removed as they successively crystallize. A dark brown mother-liquor is left, which contains nearly all the iodine: this is mixed with sulphuric acid and peroxide of manganese, and heated gently in a leaden retort *a*, Fig. 1215, of a cylindrical form,

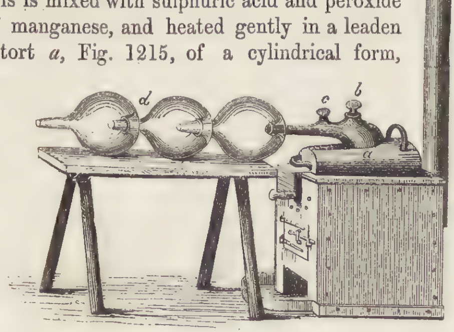


Fig. 1215. IODINE STILL.

supported in a sand bath, and heated by a small fire below. The retort has a large opening, to which a capital, *b c*, is luted, containing two openings of unequal size, *b c*, closed by leaden stopples. A series of bottles *d*, having each two openings, are luted together as shown in the figure, and are used as condensers; the prepared ley being heated to about 140° in the retort, the manganese is introduced. Iodine immediately begins to come off, and collects in the condensers. The progress of its evolution is watched by occasionally removing the stopple at *c*, and additions of sulphuric acid or manganese are made at *b* if necessary. The success of the operation depends upon its being slowly conducted, and upon the proper management of the temperature. The theory of the operation is similar to that of the process for preparing chlorine [See CHLORINE]. The manganese, however, is not indispensable in this process, for iodide of potassium or sodium, heated with excess of sulphuric acid, evolves iodine.

Professor Graham has recently examined the ashes of sea-weeds used as fuel in the island of Guernsey. "Having observed that large quantities of deep sea fuci were collected by the inhabitants, spread out to dry in the fields, then used as common fuel in their houses, and the ashes carefully saved as a valuable manure for their land, it occurred to him that these ashes might contain a larger quantity of iodine than the ordinary kelp, both on account of the source from whence the fuci were derived, and the comparatively low temperature at which the combustion was effected; for there could be little doubt that in the manufacture of Scotch kelp a portion of the iodide of sodium present was lost by sublimation." On examining these ashes they were found to be very rich in iodine.

Professor Bechi of Florence has lately invented a method for extracting iodine from mineral waters. This method is founded on the property which charcoal has of retaining iodine, and afterwards readily yielding it to other substances. The iodides contained in the mineral water are first decomposed by means of chlorine or acids, and the water is then passed through a filter containing a large quantity of calcined lamp-black: after passing through several layers of this charcoal, the water is completely deprived of its iodine. Having washed the charcoal, it is mixed with hydrated oxide of iron, placed on a filter, and water poured over it several times to remove all the iodide of iron. The solution of iodide of iron being treated with sulphate of copper, iodide of copper is formed, which, being heated in a retort with oxide of manganese and sulphuric acid, the iodine is distilled over. The charcoal used in this operation is washed with dilute hydrochloric acid, to separate any remaining oxide of iron, and thus purified, it is used for another operation.[3]

Iodine crystallizes in plates or scales of a bluish-black colour, and imperfect metallic lustre. Its density is 4·948. It fuses at 225°, and boils at 347°, emitting a vapour of a beautiful violet colour, whence

(1) A copious list of the sources of iodine is given in Gmelin's Hand-book of Chemistry, vol. ii.

(2) Elements of Chemistry, 1842.

(3) Signore Bechi's Essay gained the prize offered by the Academy of the Fine Arts of Florence, in 1849, for his answer to the question—"To find an economical and easy means of extracting iodine, not only from all its natural combinations existing in the soil of Tuscany, but also from every other artificial combination.' The Essay is given in the "Journal de Pharmacie," July 1851, and also in the "Chemist," for September 1851.

the name of this substance from ἰώδης, violet-coloured. It is slowly volatile at common temperatures, exhaling a peculiar odour something like that of chlorine. The density of the vapour is 8·716. It dissolves in about 7,000 parts of water, to which it gives a brown colour; but in alcohol it dissolves freely. It stains the skin of a deep brown, which is not permanent. It acts with energy on the animal system, and is much used in medicine.

The chief use of iodine in the arts arises from its characteristic property of producing a splendid blue colour by contact with starch. A liquid, containing one 450,000th of its weight of iodine, receives a blue tinge when a solution of starch is added to it. In order to act as a test, the iodine must be free or uncombined, for which purpose, when the presence of a soluble iodide is suspected, a small quantity of chlorine water, added to the solution, will liberate the iodine so as to allow it to act on the starch. Iodine and bromine are also used to form the film of iodide or bromide of silver in the silver plates of the daguerreotype.

Iodine unites with hydrogen, forming hydriodic acid (HI.), and with oxygen forming iodic acid, IO_5, and hyperiodic acid, IO_7.

IPECACUANHA, the root of several plants growing in South America. They all contain similar ingredients, but differ in the amount of the active or emetic principle, called *emetina*, contained in them. The best ipecacuanha is the annulated: it is produced by the *Cephaëlis Ipecacuanha*, a small shrubby plant, of which there are 3 varieties, the *brown*, the *red*, and the *grey*, or *grey-white*, also called *greater annulated ipecacuan*. This is the only sort sent from Rio Janeiro, and is sometimes called *Brazilian* or *Lisbon ipecacuan*. It is sent in bales and barrels. "The root is in pieces from 2 to 6 inches long, and about the thickness of a straw, much bent or twisted, either simple or branched, with a remarkably knotty character, owing to numerous circular depressions or clefts, which give the whole an appearance of a number of rings; and hence the term *annulated*. It consists of a central portion called *meditullium*, and an external portion called the *cortical* part. Each contains *emetina*, but by far the greater portion exists in the cortical. Of the 3 varieties of annulated ipecacuan, the brown contains 16 per cent. of emetina, while the red contains only 14 per cent." The *undulated* or *amylaceous* ipecacuan, contains only 6 per cent. of emetina, with 92 per cent. of starch. Emetina is a white, inodorous, and nearly tasteless powder.

IRIDIUM, (Ir. 98·68.) This metal is noticed in our Introductory Essay, vol. i. p. c.

IRON (Fe. 28) is more extensively diffused throughout the crust of the earth, and in greater abundance, than any other metal: indeed, it is scarcely possible to analyse an inorganic body without finding it: and its importance is equal to its abundance, for there is no other substance which possesses within itself so many valuable properties, or is so well adapted to form the tools, machines, and engines, which have assisted, and still continue to maintain, the dominion of mind over matter. Admirably adapted also to the wants of man is the position of iron ore in the earth, for it is often found in immediate connexion with the coal and the limestone flux required for its reduction: "an instance of arrangement," as Conybeare well remarks, "so happily suited to the purposes of human industry, that it can hardly be considered as recurring unnecessarily to final causes, if we conceive that this distribution of the rude materials of the earth was determined with a view to the convenience of its inhabitants."

SECTION I. —METALLURGICAL HISTORY OF IRON.

Iron was known at a very early period in man's history. We read in Gen. iv. 22, that Tubal Cain was an instructor of every artificer in brass and *iron*, and in many parts of the sacred record we have evidence of the extensive use both of iron and steel. Among the ancient Greeks bronze seems to have preceded the use of iron, and the term used to designate the smith's calling signified "a worker in bronze," a term afterwards applied also to workers in iron. Many passages in Homer show that iron was well known in his time, and there can be no doubt that the word *σίδηρος* has been correctly translated into *iron*, for in the Odyssey there is a simile commencing thus: "As some smith or brazier plunges into cold water a loudly-hissing great hatchet or adze, tempering it, for hence is the strength of iron," &c.; thus proving that the art of tempering steel was practised as it is at present in the manufacture of cutting-tools, and that the worker in iron or steel was called a brazier. In later times, steel was abundant in Greece. Æschylus (born 460 B.C.) includes all the countries on the shores of the Black Sea under the general term Scythia or Chalybia. "He speaks of the Chalybes as workers in iron, of Scythia as a land, 'the mother of iron;' and of the sword, as 'sharp iron, the bitter appeaser of strife;' 'the Pontic stranger born in fire;' and also as 'the Chalybian stranger come out of Scythia.' From this time dates the use of the word *chalybs*, in Greek, as signifying steel of the best quality; whence it passed unchanged into the Latin language, and may at the present day be recognised in our own, in the expression *chalybeate* waters, *chalybeate* medicines, &c., in consequence of some commercial transactions which took place more than twenty-three centuries ago between Greece and a country on the Black Sea."[1]

The Romans had an early acquaintance with iron. Diodorus Siculus mentions Æthalia (Elba) as being celebrated, as it now is, for the richness and abundance of its iron ores. Pliny the elder, after enumerating many of the uses of iron in his time, says, "Yea, in one word, we use it to all other necessary uses of this life." This writer refers to Spain as being celebrated for its iron manufactures. But although iron was well known to the Romans, it

(1) In Mr. Arthur Aikin's "Illustrations of Arts and Manufactures," published in 1841, are four excellent papers, read before the Society of Arts, entitled, "The Antiquarian and Metallurgical History of Iron."

appears from the evidence afforded by the excavations of Pompeii and Herculaneum, that articles of bronze were in general use in the middle of the first century, when those cities were overwhelmed. It is difficult to imagine how bronze and iron should ever be considered as equally applicable to the same uses. " In all the Latin writers, *ferrum*, iron, is the most common name for a sword, but the swords which have been found in these towns are of bronze, as also are the points of spears. Poll-axes and other sacrificing instruments have been found of the same material: even surgeons' instruments, 40 in number, some with cutting edges, and all of bronze, were discovered."

The earliest method of smelting iron seems to have been in furnaces erected on the summits of hills for the sake of currents of air, the furnaces being perforated on all sides with holes, through which the air was driven when the wind blew: the ore was interstratified with charcoal, large quantities of which were added from time to time, and the operation lasted two or three days. Mungo Park, in his Travels in Africa, describes one of these furnaces, which is probably a type of the ancient model. A furnace similar to this was probably used by the ancient Britons, who are supposed to have obtained their knowledge of the art of smelting iron from the Phenicians, who traded with them for tin. Strabo mentions iron as one of the exports of Britain, so that it seems pretty evident, that prior to the Roman invasion the Britons were acquainted with the art of working iron: indeed, the scythes, hooks, broadswords, and spears, with which they opposed their invaders, are evidences of the fact.

Mr. Mushet, in his valuable "Papers on Iron and Steel," remarks on the extreme slowness of these air-bloomeries. " A long and continued cementation of the ore in contact with the fuel was necessary to dispose the metallic particles to unite. A too rapid exposure to a high temperature would be apt to unite a considerable portion of oxygen with the ore, which in this way would acquire a considerable degree of fusibility: this would not only diminish the quantity and quality of the iron, but retard the general operation. To render the quality of the iron homogeneous, masses of iron ore would be used as nearly of one size as possible, which would give rise to a rejection in part of the small, or dust ore, generally the richest of the vein. That this practice prevailed to a considerable extent in Gloucestershire, is evident from the large quantities of small *mine*[1] found from time to time in the old caverns or weeldons of the mountain limestone formation. These acknowledged evils undoubtedly affected the economy and prosperity of the trade, until some more fortunate or more ingenious worker applied the bellows to the art of iron making, which gave rise to the blast-blowing, and occasioned a great revolution and improvement in the fabrication of iron."

When the Roman Conquest was secure the useful arts were carried on in Britain to an extent before unknown in the island. After the arrival of Adrian, (A.D. 120,) the *fabrica*, or great military forge, was established at Bath: and similar establishments were formed in different parts of the country. The situation of Bath was well adapted to such an establishment, from its vicinity to the hills of Monmouthshire and Gloucestershire, where iron ore and wood were plentiful. There is abundant evidence of the industry of the Romans in working the iron mines of Britain until their final abandonment of the island about A.D. 409. Immense beds of iron cinders have been discovered in the Forest of Dean in Monmouthshire, in Yorkshire, and other counties, among which have been found Roman coins and the remains of altars inscribed to the god who presided over iron. Many of these heaps are called *Danes' cinders,* from the idea, probably a correct one, that during the occupation of England by the Danes they carried on the smelting of iron extensively. From the rude method of smelting in these early times, a portion only of the ore was reduced, and it has been found profitable in modern times to smelt these cinders over again. Mr. Mushet states, that for nearly 200 years the blast-furnaces in the Dean Forest used nearly one-half of the furnace burden of these slags or cinders, which were found highly advantageous to mix with the calcareous ores of the district.

In the interval between the Saxon and the Norman conquest scarcely any notices of iron are to be found. The Anglo-Saxons bestowed especial honour on the best artificers of swords, arms, and armour. Gloucester was long celebrated for its iron forges, and it is mentioned in Doomsday-book, that scarcely any other tribute was required from that city than 36 dicars (of 10 bars each) of iron, and 100 iron rods for nails or bolts for the use of the royal navy. From the Conquest to the death of John, iron and steel were imported from Germany and other countries, the German "merchants of the steel-yard" probably deriving that title from the article imported by them, and sold at a place called "the Steel Yard." The art of making defensive armour was during this period carried to great perfection, and a smith or armourer was attached to the establishment of every knight.

Wood-charcoal still continued to be used in smelting iron, so that the iron mines were all situated in the wooded districts of England. Iron must have been scarce, for in the 28th of Edward III. its exportation was prohibited. Up to this time all articles of iron were forged, the art of casting not having been invented, and it has not been determined at what time castings first came into use. It appears, however, that towards the end of Elizabeth's reign, the English first attempted to substitute iron for bronze in the casting of cannon, but the art was probably practised long before in the production of other articles.[2]

During the 14th and 15th centuries England was supplied by Germany and Spain with various articles in iron and steel. In 1483 the home manufacturers complained of this to the Legislature, which led to the passing of an act prohibiting the importation of a variety of articles which could be made at home.

(1) The technical word for *ore.*

(2) See Scrivenor's History of the Iron Trade. 1841.

In the reign of Elizabeth we find the ingenious Camden lamenting the decay of our forests in consequence of the extension of the iron trade. Several attempts were made in this reign to lessen the consumption of wood, and to limit the erection of iron-works; and it was not until the scarcity of charcoal had stopped many iron-works, that attempts were made to smelt iron ore by means of pit coal. Prior to the year 1272 coal had been wrought at Newcastle, and large quantities of it continued to be exported annually to Holland and the Low Countries for the use of the smithy, but it was not thought profitable to smelt by means of coal until Dud Dudley set the example. The name of this person deserves to be enrolled on the same bright page as that which contains the names of Brindley, Arkwright, Watt, and other illustrious men who have so greatly contributed to raise England to her present high position as a manufacturing and commercial nation. It appears, from the interesting account which he has left of his own proceedings, that in 1619, at the age of 20, he quitted the University of Oxford in order to manage three iron-works of his father's in the chase of Pensnet in Worcestershire. Wood having become scarce in the neighbourhood, and pit coal abounding near the furnace, he determined to make trial of it, and was so successful, that he applied for a patent for his invention, which was granted for 31 years. In the year after the date of the patent, Dudley's iron-works were destroyed by a great flood, "to the joy of many iron-masters, whose works escaped the flood, and who had often disparaged the author's inventions because he sold good iron cheaper than they could afford it, and which induced many of the iron-masters to complain unto King James, averring that the iron was not merchantable. As soon as the author had repaired his works and inventions, to his no small charge, they so far prevailed with King James, that the author was commanded, with all speed possible, to send all sorts of bar-iron up to the town of London, fit for making of muskets and carbines; and the iron being so tried by artists and smiths, that the iron-masters and ironmongers were all silenced until the 21st of King James."

In this year, 1624, was passed the justly celebrated act for the abolition of monopolies, except patent rights for 14 years to the first inventors of processes or manufactures. Dudley's patent was limited to this term, and he says, that he "went on cheerfully, and made annually great store of iron, good and merchantable, and sold it at 12*l*. per ton. He also made various cast-iron wares, such as brewing cisterns, pots, mortars, &c., better and cheaper than any yet were made in these nations with charcoal." But so slow are ordinary minds to adopt new ideas, or to vary the ordinary routine of their proceedings, that the iron-masters continued to oppose, and succeeded in getting poor Dudley turned out of his iron-works. How this was effected, would, he says, be "over long to relate;" but we can well imagine the long course of opposition, of petty annoyance and vexation, inflicted by his rivals, to say nothing of positive wrongs, of combinations among masters and men to oppose a man who was adopting a process the value of which they had not the sagacity to perceive. Dudley proceeded to Himley furnace in Staffordshire, "where he made much iron with pit-coal; but wanting a forge to make it into bars, was constrained for want of stock to sell the pig-iron unto the charcoal iron-masters, who did him much prejudice." After this he erected a large furnace, "27 feet square, all of stone," at Hascobridge, in Staffordshire, "where he made 7 tons of iron per week, "the greatest quantity of pit-coal iron that ever yet was made in Great Britain. Near which furnace the author discovered many new coal mines ten yards thick, and iron mine under it, according to other coal works; which coal works being brought unto perfection, the author was, by force, thrown out of them, and the bellows of his new furnace and invention, by riotous persons, cut in pieces, to his no small prejudice and loss of his invention of making of iron with pit-coal, &c.; so that being with law-suits and riots, wearied and disabled to prosecute his art and invention at present, even until the first patent was extinct." Poor Dudley lost most of his property, and was imprisoned for debt; and when Cromwell came into power, he had the mortification of seeing a patent granted to one Captain Buck, for making iron with pit-coal: he states that Cromwell and many of his officers were partners in the scheme, which, however, failed. At the Restoration, Dudley presented a memorial to Charles II.; it is an exceedingly interesting document, and contains a masterly epitome of the iron trade up to the time of its composition. It appears strange to us that the force of such reasoning as the following could be resisted, especially when the prize to be gained by yielding to it was iron! After stating that God of his infinite goodness had bestowed upon this country abundance of iron, coal and lime, and that the wood had long been exhausted, he proceeds thus:—"Now, if the coals and ironstone so abounding, were made right use of, we need not want iron as we do; for very many measures of ironstone are placed together under the great ten yards thickness of coal, and upon another thickness of coal, two yards thick, not yet mentioned, called the bottom coal, or heather coal, as if God had decreed the time when and how these smiths should be supplied, and this island also with iron; and most especially, that this coal and ironstone should give the first and last occasion for the invention of making iron with pit-coal, no place being so fit for the invention to be perfected in as this country, for the general good; whose lands did formerly abound in forests, chases, parks, and woods, but exhausted in these parts."

Dudley does not seem to have been successful in his application, and with him died, for a time, the art of making iron with pit-coal. The art of converting coal into coke was known and is described by Dr. Plot, in his History of Staffordshire, published in 1686, who says, that it is "fit for most other uses, but for smelting, fining and refining of iron, it cannot be brought to do, though attempted by the most

skilful and curious artists." Our chemists at this time were too much occupied in attempting to transmute the baser metals into gold, to attend to the apparently common-place and inglorious problem, how to smelt iron with pit-coal.

It was not until 1713, that we hear of any further attempts in this way, when Mr. Darby, of Colebrook Dale, is referred to as smelting iron with pit-coal. The process, however, must have been ill understood, and little known, for in 1747, it is stated in the Philosophical Transactions, as a sort of curiosity, that " Mr. Ford, from iron ore and coal, both got in the same dale, makes iron brittle or tough, as he pleases; there being cannon thus cast, so soft as to bear turning like wrought-iron."

Although the demand for iron was every year rapidly increasing, the yield of our iron furnaces was almost as rapidly diminishing. Instead of relying upon our inexhaustible supply of coal and iron to meet the demand, our ancestors imported vast quantities of iron from Russia and Sweden. At length, however, the steam-engine, under the guidance of Watt, entered into the service of industry, and gave such a stimulus to our great branches of manufactures, that vast systems of iron machinery were being constantly demanded. Then it was that the coal and the iron-stone were made to act upon each other, and the impulse once given, the manufacture advanced with accelerated velocity; and from 61,300 tons produced in 1788, we have in 1851 the enormous amount of 2,500,000 tons.

While the change in fuel was being brought about, the manufacture declined so rapidly, that in 1740, the number of furnaces in England was 59, being only three-fourths of their previous number, and the annual produce was only 17,350 tons. As the use of coke became understood, the manufacture revived, so that in 1788 the number of tons of pig-iron produced was 61,300, as already stated; in 1796, the quantity was increased to 108,793 tons; in 1806 to 250,000 tons; in 1820, to 380,000 tons; in 1827, to 654,500 tons; in 1845, to 1,250,000 tons; and in 1851, to 2,500,000 tons.[1] In this year, the exports of pig-iron were upwards of 1,200,000 tons, besides tin plates, hardware, cutlery and machinery, bearing a total value of £10,424,139.

Improvements in the smelting of iron have been great and important, as will appear from the following statement, of the average produce of each furnace annually and weekly.

	ANNUALLY.			WEEKLY.	
	tons.	cwt.	qrs.	tons.	cwt.
In 1740	294	1	1	5	13
1788	796	2	0	15	6
1796	1,046	0	0	20	2
1827	2,460	0	0	47	6
1845	5,200	0	0	100	0

At the present time, the average weekly yield of a furnace is from 110 to 120 tons of pig-iron; but in an emergency, as much as 200 tons have been produced from one furnace in a week. At the time we write (May 1852), some of the Scotch and Welsh furnaces are producing the latter quantity.

The locality of the manufacture has also been affected by the change of fuel. In 1740, Gloucester was the largest iron producing county in Great Britain. Sussex had the greatest number of furnaces; there were a few in Kent, and a few in the Midland Counties, and along the Welsh borders. After the introduction of coke, the coal counties assumed a far greater importance in connexion with iron than the woodland districts had done. Shropshire, Staffordshire, and South Wales became important; for some years past the greatest quantity of iron has been produced in South Wales; although Shropshire and Staffordshire have produced a superior metal. Scotland also has competed successfully in the production of this all-important metal.

" In whatever point of view the iron trade may be considered with regard to this country," says Mr. Mushet, " the advantages derived from its progress have been great; whether we consider it as having cleared the country of vast tracts of wood, affording at the same time an ample indemnification for the labour bestowed,—the consequent improvement in climate, and the spread of agriculture,—as having placed us at the head of the manufacturing countries of Europe,—as affording us at all times a plentiful supply for the construction of every species of machinery,—or, as having been a source of wealth to many individuals, and, at the same time, affording a competent recompense for the labour of a number of our fellow-creatures."

SECTION II.—IRON AND ITS COMPOUNDS.

Iron is employed in the arts in three different states,—as *crude* or *cast-iron*, as *steel*, and as *wrought-iron*, the differences depending upon the relative amounts of carbon with which the metal is combined. Cast-iron contains a larger proportion of carbon than steel, and steel more than wrought or malleable iron, which ought to be quite free from carbon. In practice, however, this is never found to be the case, although the best malleable iron retains only a very minute portion of carbon. The iron of commerce is also contaminated with traces of silicium, sulphur, and phosphorus, the presence of which greatly influences the quality of the metal.

Pure iron may be obtained by introducing into a Hessian crucible 4 parts of fine iron wire cut small, and 1 part of black oxide of iron: this is to be covered with a mixture of white sand, lime, and carbonate of potash in the proportions used for glass making, or pulverized hard glass may itself be used, and a cover being closely applied, the crucible is to be subjected to an intense white heat. A button of pure metal is thus obtained, the traces of carbon and silicon present in the wire having been removed by the oxygen of the oxide, and combining with the vitreous flux form a slag. Pure metallic iron may also be obtained by passing hydrogen gas over one

(1) Of this quantity ⅓ was used in castings, the remainder in malleable manufactures. To produce it required 7,000,000 tons of ore, 2,700,000 tons of limestone, and 13,000,000 tons of coal. From 650,000 to 700,000 persons are engaged in the manufacture. Steam-power is also largely used.

of the oxides of the metal contained in a tube of porcelain or hard glass heated to dull redness. The reduced metal will be in a spongy state, and by exposure to the air will absorb oxygen so greedily, as to take fire and become converted into a sesquioxide; but if the reduction be made at a high temperature, the particles cohere, and the metal does not ignite on exposure to the air.

Pure iron has a white or bluish grey colour, and acquires a brilliant surface by polishing. Its sp. gr. is 7·8, and its crystalline form is probably the cube. The texture of commercial iron varies according to its mode of preparation. Pure iron, which has been drawn out under the hammer in all directions, has a finely granular structure, but when rolled into long bars, as usually sent into the market, the texture is fibrous in the direction of the length. The fibres may be made evident by the fracture of a bar of iron under tension, or by acting upon it with dilute muriatic acid. Upon the perfection of this fibre much of the strength and value of iron depends, although by skilful management this *silky* character may be imparted to common varieties of the metal. The fibrous character is not, however, necessarily permanent, for after a time the metal has been found to assume a crystalline appearance, especially when subjected to constant vibration, as in the tension rods of suspension bridges, the axles of locomotives and of railway wagons, &c.[1]

Iron is the most tenacious of all the metals, a wire of $\frac{1}{36}$th inch in diameter bearing a weight of 60 lbs. It requires the strongest heat of a wind furnace to fuse it, but when combined with a small proportion of carbon it fuses at a much lower temperature. Before it becomes liquid, or when liquid before it becomes solid, iron passes through a soft or pasty condition, and hence crystallizes with difficulty; but when slowly cooled in large masses, indications of a cubical crystallization are obtained. At a full red-heat iron may be hammered into any form, and at a white heat, two pieces pressed or hammered together cohere: but in order that this operation, which is termed *welding*, may be successful, the surfaces must be in the metallic state, free from oxide; but as the oxygen of the air combines rapidly with iron heated to the welding point, it is usual to sprinkle a little sand over the heated metal, and this combining with the superficial film of oxide forms a fusible silicate, which forms a kind of varnish, and protects the metal from the air. On taking the bars out of the fire this silicate is by a rapid motion shaken off, and clean metallic surfaces can thus be brought into contact, or the silicate is forced out by the pressure applied in uniting them.

Iron, nickel, and cobalt, are the only metals which are evidently magnetic at ordinary temperatures. A piece of pure iron immediately becomes magnetic in the vicinity of a magnet, but it loses all magnetic properties as soon as the magnet is removed to a distance. Magnetism is developed in steel more slowly, but is retained more permanently; and a bar of steel rubbed by a magnet becomes itself a permanent magnet. The magnetic properties of iron diminish rapidly as the temperature rises; a mass of iron heated to redness has no action on the magnetic needle, but it regains its magnetic properties in cooling.

Iron does not oxidise in dry air, nor even in dry oxygen, at common temperatures; but in moist air it becomes covered with a scaly coating of black oxide or rust. The presence of carbonic acid in air greatly assists the operation, for the iron becoming changed into the carbonate of the protoxide absorbs a new portion of oxygen and is thus transformed into the hydrate of the peroxide of iron. The carbonic acid disengaged facilitates the oxidation of a new portion of metallic iron. When once iron has begun to rust at one point of its surface the rust spreads rapidly round this point in consequence of a galvanic action, which accelerates the oxidation. The small spot of rust forms the two elements of a voltaic pile, in which the iron is positive, and thus acquires for oxygen an affinity sufficiently strong to decompose the moisture of the air, hydrogen being set free. Rust also contains small portions of ammonia, the odour of which becomes evident by heating it with potash. Ammonia, which consists of hydrogen and nitrogen, is formed when these two elements come into contact in a liquid, in what is called the *nascent state*, that is, in the very act of separating from a body under decomposition. Now the moisture of the air containing a portion of air, and consequently a portion of nitrogen in solution, this moisture coming in contact with rust of iron, is decomposed, and the hydrogen and nitrogen which are set free at the same moment combine to form ammonia. The ammonia is retained by the peroxide of iron, which acts towards it as a weak acid would do.[2] Iron becomes soon rusty in pure water, but not in water containing minute portions of carbonate of soda or of potash. It is common now to preserve iron from rust by coating it with a thin layer of zinc, forming what is called *galvanised iron*, by a process explained under AMALGAM.

When iron is heated to redness, in contact with the air, a film of oxide forms, which falls off under

(1) A few years ago Mr. Charles Hood brought before the Institution of Civil Engineers some interesting facts respecting the conversion of fibrous into crystalline iron. According to him, the tough and fibrous character of wrought-iron is entirely produced by art, and there is a constant tendency in such iron, under certain circumstances, to return to the crystallized state, which state is not necessarily dependent upon time for its development, but is determined by other causes, the chief of which is *vibration*. *Heat*, within certain limits, though greatly assisting the rapidity of the change, is certainly not essential to it; but *magnetism*, induced either by percussion or otherwise, is necessary to the change. It was shown by specimens, that in the same rod or bar of wrought-iron, the crystallization is far more extensive in those parts most exposed to vibration. In the parts not so exposed, the texture remained fibrous.

(2) It was formerly supposed that when a steel or iron weapon, on which certain stains were observed, was heated in contact with potash, and emitted an ammoniacal odour, that this was sufficient evidence that such stains were produced by blood. Such evidence as this has been produced in criminal trials, but we now see that the exposure of an iron or steel blade to moist air is sufficient for the production of ammonia.

the hammer. When sparks are struck by the old-fashioned flint and steel, minute portions of the metal are struck off, and being heated by the friction of the flint the oxygen of the air seizes them, and they enter into combustion. If a piece of iron be struck with a flint over a sheet of white paper, it will soon be covered with small black grains capable of being attracted by the magnet, and which are in fact small globules of magnetic oxide of iron.

Four compounds of iron and oxygen are commonly described. The first is the *protoxide* (FeO) which acts as a powerful base completely neutralizing acids. It is seldom met with in a separate state, in consequence of its tendency to absorb oxygen and pass into the sesquioxide: its soluble salts have usually a delicate pale green colour, and a nauseous metallic taste. The *peroxide* (Fe^2O_3) is a feeble base, and may be prepared by precipitating a solution of persulphate or perchloride of iron by excess of ammonia, and washing, drying and igniting the yellowish brown hydrate thus produced. In the state of powder this oxide has a full red colour and is used as a pigment, for which purpose it is prepared by calcining the protosulphate, the tint varying with the temperature. This oxide dissolves in acids, forming a series of reddish salts. It is not acted on by the magnet. The *black oxide* (Fe_3O_4), also known as the *magnetic oxide* or the *lodestone*, does not form salts. *Ferric acid* (FeO_3) is prepared by heating a mixture of pure peroxide of iron with 4 parts of dry nitre; by subsequent treatment a solution of ferrate of potash is formed, which is not permanent, but when baryta is added a deep crimson insoluble ferrate of that base is formed, which is permanent.

By dissolving iron in hydrochloric acid, green crystals of *protochloride* ($Fe\,Cl$) may be formed, and by dissolving peroxide of iron in the same acid the red hydrated crystals of the sesquichloride (Fe_2Cl_3) may be produced. The *protiodide* (FeI), important in medicine, is formed by digesting iodine with water and metallic iron. There are several compounds of iron and sulphur. The *protosulphuret* (FeS) is formed by bringing a white hot bar of iron in contact with sulphur; but the usual method is to project into a red hot crucible a mixture of $2\frac{1}{2}$ parts of sulphur, and 4 parts of iron filings, excluding the air as much as possible. It is a blackish brittle substance attracted by the magnet. The *bisulphuret* (FeS_2) will be noticed among the ores of iron.

Compounds of iron with phosphorus, carbon and silicon exist; the *carburet* in cast-iron and steel, which it renders more fusible; the *silicon* compound is also found in cast-iron, which it probably renders brittle, as does also phosphorus, the presence of which is supposed to confer the property technically called *cold-short*, while the presence of sulphur renders iron *hot-short*.

Protosulphate of iron or *Green Vitriol*, $FeO, SO_3, + 7HO$. This important salt may be obtained by dissolving iron in dilute sulphuric acid; but it is usually prepared on a large scale from iron pyrites, as will be noticed presently. Sulphate of iron slowly effloresces and becomes peroxidized in the air; it is soluble in about twice its weight of cold water. The *persulphate*, $Fe_2O_3, 3SO_3$, does not crystallize. The *protonitrate* FeO, NO_5, is not a very stable compound; the *pernitrate* is formed by pouring nitric acid, slightly diluted, upon iron; it is a deep red liquid used in dyeing. The *protocarbonate*, FeO, CO_2, is formed by mixing solutions of the protosalts of iron and alkaline carbonates: it exists in the common *clay iron-stone*, and is often found in mineral waters.

Section III.—Native and Meteoric Iron and Iron Ores.

Native iron is of rare occurrence: it has been found in Saxony and elsewhere, forming the centres of stalactiform masses of brown hematite. These metallic kernels appear to have been produced by the decomposition of a portion of the oxide in which they are imbedded, a change which may have been brought about by electro-chemical agency.[1] Native iron is also produced by the spontaneous ignition of seams of coal in the neighbourhood of ferruginous deposits, producing small button ingots with a finely striated surface; they are very hard and fine grained, and are known by the name of *native steel*. Large masses of metallic iron exist in different parts of the world, and other similar masses have been observed to fall from the atmosphere. These *meteorites* differ in structure and composition from native iron: they always contain nickel, which is not found in the ores of iron, and they are covered with a kind of black siliceous varnish which protects them from the air; when this is removed the metal easily oxidises. Some of the masses of meteoric iron have been used by the inhabitants of the countries where they fell, in making knives, spears, and other instruments. There is a mass in South America estimated at 30,000 lbs. weight; one in Siberia, 1,600 lbs.; and one at Agram, in Croatia, which fell from the sky in 1750, in the presence of many witnesses. Numerous *aërolites* have at different times fallen from the atmosphere; they contain other substances in addition to iron. A stone, which fell at Château Renard on the 12th June, 1841, was found, by M. Dufrénoy, to contain per cent. silica, 30·13; alumina, 3·82; magnesia, 38·13; lime, 0·14; oxide of iron, 29·44; oxide of manganese, a trace; potash, 0·27; soda, 0·86; sulphur, 0·39; iron, 7·70; nickel, 1·55.

The ores of iron are very numerous, and we can only refer to a few of the most important in a metallurgical point of view.

One of the most universally diffused ores of iron is the *magnetic:* it occurs in granite, gneiss, mica-slate, clay-slate, syenite, hornblende, and chlorite; also in the limestone formations. Nearly all the

(1) Mr. John Arthur Phillips, in his recently published *Manual of Metallurgy*,—an excellent guide-book to all persons interested in the chemistry of the metals,—explains this change by supposing, "that the whole or a portion of the iron formerly existed in the form of iron pyrites, (bisulphuret of iron,) which, becoming oxidised, not only produced a certain amount of the soluble sulphate of iron, but also generated by chemical action an electric current of sufficient power to precipitate a part of the iron in the metallic form."

Swedish iron is obtained from this ore. It is also abundant in the Island of Elba and in the United States of America. The primitive form of magnetic iron ore is a cube, but it often occurs in octahedrons and dodecahedrons. Its cleavage is often parallel to the faces of the octahedron. It is brittle, of an iron-black colour, and leaves a black streak. Density, 5·0 to 5·1. It is strongly attracted by the magnet, and sometimes possesses independent polarity. It contains iron, 71·78, and oxygen, 28·22; or peroxide of iron, 69, and protoxide, 31.

Specular iron; Red Hematite.—The crystals of this ore are generally complex modifications of the rhombohedron, of a dark steel-grey colour, opaque except in very thin laminæ, when they are transparent, and of a deep blood-red tinge. It leaves a reddish streak, and the density varies from 4·8 to 5·3. Pure specular iron consists solely of peroxide of iron.

There are several varieties of red iron ore. Fibrous iron, or *red hematite,* occurs in fibrous reniform masses. When there are no indications of columnar structure it is termed *compact,* and if mixed with argillaceous matter, it is known as *red ochre.* When specular iron has a foliated structure, it is called *micaceous.* Specular iron ore is also called *oligistic iron, iron glance,* and *rhombohedral iron. Jaspery clay iron ore* is of a brownish red colour, with a large flat conchoidal fracture: when it occurs in small flattened grains it is called *lenticular clay iron.*

The purer varieties of this ore occur in the older formations: the argillaceous ores are usually met with in secondary rocks. The Island of Elba furnishes beautifully crystallized specimens: brilliant crystals are also found in the fissures of volcanic districts.

Red hematite is found in reniform masses in Cornwall, at Ulverstone in Lancashire, and other places. [See HEMATITE, Fig. 1117.] This ore, when ground to powder, is used as a pigment, and also for polishing metals.

The various ores of the peroxide are of great importance as a source of iron, although they do not yield so large a per-centage of metal as the magnetic oxide: the specular varieties are also somewhat refractory in the furnace; but by a proper mixture with other ores they yield an excellent iron.

Brown iron ore is, as its name implies, of a brownish colour, and it affords when crushed a yellow powder. Its density varies from 3·8 to 4·2. When pure it yields 55 per cent. of metallic iron. It is a hydrated peroxide, chiefly found in sedimentary rocks. Its forms are often pseudomorphic,[1] and these may be due to the decomposition of iron pyrites when it assumes the cube or octahedron. It also occurs in rhombohedrons from the substitution of carbonate of iron, as also in the moulds left by the decomposition of shells and madrepores, the shapes of which are assumed by the mineral. It also forms stalactites and hollow reniform masses. *Pea-iron* is one of its forms, found in the oolitic formations. When mixed with aluminous matter it acquires a soft texture, and is known as *yellow ochre.*

This ore is in some countries, France, for example, the most abundant source of iron; and when washed to separate the lighter impurities, it yields an excellent material for the manufacture of iron. But when beds of oolitic iron are found to alternate with calcareous deposits, the metal produced is *cold-short,* in consequence of the phosphorus derived from the organic matter of the chalk.

Iron pyrites, or bisulphuret of iron, $Fe\,S_2$, containing, iron, 45·74 per cent., and sulphur, 54·26, crystallizes in the cubic system, frequently in pentagonal dodecahedrons, also in octahedrons and cubes more or less modified. The colour is bronze-yellow, with a metallic lustre; the streak, brownish-black; sp. gr. 4·8 to 5·1: it is brittle, and strikes fire with steel, whence the name *pyrites.* The cleavage is parallel to the faces of the cube and octahedron. It occurs in small cubical crystals, Fig. 1216, in veins, and in various slate-rocks and coal-fields, and in globular concretions in indurated clay and chalk. It also accompanies the ores of all the other metals, and in many cases replaces the remains of animal and vegetable forms. The crystals from Elba are very fine: very large cubes are also obtained from Cornwall, and large perfect octahedrons from Sweden. It is also found in many of the coal-fields, where, by its oxidation and conversion into sulphate of iron, the temperature is in some cases so much raised as to ignite the coal.

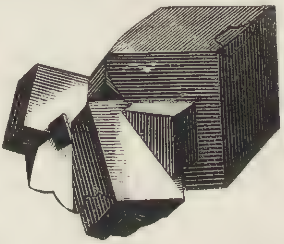


Fig. 1216.

Iron pyrites is not used as a source of metallic iron; but is frequently employed as a source of sulphur in the manufacture of alum and sulphuric acid. [See ALUM—SULPHURIC ACID.]

White-iron pyrites has the same composition as the above, but crystallizes in forms derived from the right rhombic prism. It often occurs in radiated crystallized masses, called *cockscomb pyrites.* It occurs in most of our mineral districts. There is also a *magnetic iron pyrites,* and an *arsenical iron pyrites.*

We must also refer to *chrome-iron,* which occurs so abundantly in the Shetland Islands, and is used for making chromate and bichromate of potash; and to *tungstate of iron—Wolfram*—which has been lately employed for making tungstate of lead, to be used as a pigment instead of the white-lead now in use.

The ore from which the greater portion of the iron manufactured in this country is obtained, is the *carbonate.* It occurs in rhombohedrons and six-sided prisms, resembling carbonate of lime: also in glo-

(1) A *pseudomorphous* crystal, (from ψευδὸς, false, and μορφὴ, a form,) is one that has a form which is not known in the species to which the substance belongs. There are many causes for pseudomorphism, as when a cavity left empty by a decomposed crystal, is refilled by another species by infiltration, and the new mineral assumes the external form of the original mineral. Crystals may also be incrusted over by other minerals.

bular concretions, or lenticular masses. When pure, it consists of protoxide of iron 61·37 per cent., and carbonic acid 38·63. It is known by the various names of *Siderite, Sparry iron, Spathose iron, Brown spar,* &c. Sparry-carbonate of iron, Fig. 1217, often accompanies other metallic ores, such as those of lead or copper. In Styria and Carinthia the beds occur in gneiss; in the Hartz, in grey-wacke; but the English deposits are confined to the coal-formation: it usually occurs in horizontal strata, subject, however, to the same inclination as the other strata which it accompanies. It is generally found imbedded in schistous clay, more or less compact, which moulders away when exposed to the air. Hence its well-known name of *clay ironstone.* It is of grey, blue, brown, or black colours, with sp. gr. from 2·8 to 3·5, and hardness from 3·5 to 4·5. It occurs, as already stated, chiefly in slate, clay, or marls, in layers or nodular masses, often containing fossil plants, or other organic bodies, which seem to have attracted the carbonate of iron. In these nodules, crystals of siderite, calc-spar, celestine, barytes, quartz, pyrites, blende, and galena often occur. This variety is found occasionally in the transition rocks, but especially in the coal formation of Britain, Belgium, and Silesia in vast abundance. It is more rare in the oolite and chalk in Northern Germany, and England; and in the brown coal of Radnitz in Bohemia, and other places, frequently forms petrifactions of wood. The ironstone is met with under two different forms: in regularly connected strata, called *bands,* and in strata of detached stone, formed in distinct masses, from the size of a small bullet to that of lumps of several hundred pounds weight. What is called *black-band,* or *carbonaceous* ironstone, is also a carbonate of iron, containing carbonaceous matter in addition to the ordinary earthy substances found in all argillaceous ironstones. The difference between black-band and clay ironstone will be seen from the analysis of varieties of the two.

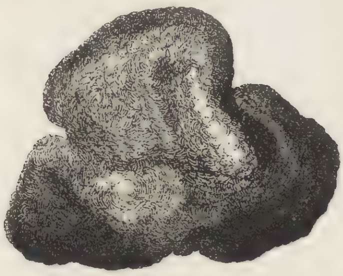


Fig. 1217.

The carbonaceous matter in the black-band varieties, Nos. 1 to 5, materially assists in the reduction of the ores. Mr. Mushet says, in referring to this ore, that instead of 20, 25 or 30 cwt. of limestone formerly used to make a ton of iron, the black band only requires 6, 7, or 8 cwt. This arises from the extreme richness of the ore when roasted, and from the small quantity of earthy matter contained in it, which renders the operation of smelting the black-band with hot blast more like the melting of iron than the smelting of an ore. When properly roasted, its richness ranges from 60 to 70 per cwt., so that little more than 1½ ton is required to make a ton of pig-iron; and as 1 ton of coal will smelt 1 ton of roasted ore, it is evident that when the black band is used alone 35 cwt. of raw coal will produce 1 ton of good grey pig-iron.

The following is the composition of the celebrated *Black-band,* (Nos. 1 to 5,) and other argillaceous iron ores of Scotland and Wales.

	Carbonate of iron	Carbonaceous matter.	Earthy matter.	Metallic iron in carbonate.	
1.	70·0	23·0	7·0[1]	33·7	Black Band, Lanarkshire.
2.	51·04	22·16	26·80	24·6	Cwan Avon bed, S. Wales.
3.	63·9	10·0	26·1	30·7	Maesteg Valley. Upper bed, Upper division.
4.	79·9	6·6	13·5	38·5	Ditto, Lower division.
5.	79·5	16·4	4·1	38·4	Beaufort, Ponty pool, 4 inch band.
6.	86 0	...	14·0	41·5	Ystradgunlas, Upper vein.
7.	72·4	...	27·6	34·9	Ditto, another bed.
8.	75·4	...	24·6	36·4	Pendaren, Red vein.
9.	60·9	...	39·1	29·4	Aberfergwm, Nodules.
10.	55·5	...	44 5	26·6	Pendaren, Jack vein.

The different kinds of ironstone are known by various local names, many of which are given by Mr. S. H. Blackwell, in his catalogue of the series of iron ores contributed by him to the Great Exhibition, and referred to in our Introductory Essay, p. lxxxvi. From this instructive list we gather the following particulars respecting the iron-making districts of England and Wales.

South Wales is the most important iron-making district in the world. Its coal-field extends over an area of upwards of 800 miles, and from its extent, and the varied character of its numerous beds of coal, and its measures of ironstone and black-band, it may be considered as the most important of all our coal-fields. The number of furnaces now in blast is 143, averaging about 100 tons of iron each per week: or a gross annual production of 700,000 tons, and requiring 2,000,000 tons of ironstone, which is principally furnished from this coal-field. The annual production of coal is estimated at from 5 to 6 million tons. In 1796, the annual production of iron in South Wales was 34,011 tons; and in 1823, 182,325 tons; since which time the production has been more than trebled. In 1851 it was 750,000 tons.

The production of iron in North Wales is very limited: the coal-seams are thin, but good in quality, and the ironstones, although lean, furnish very good iron.

In Shropshire, the annual production of iron is about 90,000 tons. The quality is very good. This field was one of the first important iron-making districts of the kingdom; but from its limited extent the production has not increased for a long period.

The Dudley division of the South Staffordshire and Worcestershire coal-field is principally celebrated for its ten-yard or thick coal. When undisturbed by faults, and of average quality, this bed of coal, with the associated thin coals and ironstones, is worth at

(1) This includes silica, alumina, and a trace of lime.

least 1,000*l.* per acre. The quality of the iron is very superior. The *Gubbin* and *White* ironstones are the principal ironstones of this district. The Gubbin measures average about 1,500 tons per acre: the White ironstone varies both in quantity and richness; it yields from 1,000 to occasionally 3,000 tons per acre; but 1,500 tons may be taken as about the average.

In the Wolverhampton district the iron occupies a position in the general coal series below the thick coal of the Dudley district, and attains a much greater thickness and importance than at Dudley. The ironstones are all of good quality, averaging from 30 to 35 per cent. of metal. From the low cost at which they are generally raised, the number and variety of the measures of coal and ironstone contained in so small a space of ground, and the superior quality of the iron produced, the Wolverhampton division of the South Staffordshire coal-field may be considered as one of the most important, in proportion to its area, of any of our iron-making districts.

The annual production of iron in South Staffordshire and Worcestershire is nearly 600,000 tons. It may be regarded as the second iron-making district in the kingdom; for although the production of pig-iron in Scotland is equal to that of this district, yet it far surpasses Scotland in the manufacture of wrought-iron; while the superior quality produced also gives it pre-eminence over that of Wales.

North Staffordshire produces only about 55,000 tons of iron, but it is of great importance from the vast quantities of ironstone which it contains, and the large quantities which it sends to the South Staffordshire and the North Welsh iron districts. No other known coal-field contains anything like an equal number and extent of iron-measures. In consequence of so large a proportion of the cheapest worked ironstone measures being black-band or carbonaceous, and also from the inferior quality of its coals, the iron of this district is inferior.

In the northern district of Yorkshire the annual production of iron is about 25,000 tons, and the quality very superior. The southern district produces about 20,000 tons.

The annual production in Derbyshire is about 60,000 tons. Many of the beds of ironstone lie in such a thickness of measure as only to be workable to advantage by open-work or bell-pits, in which case the produce per acre is often very large; in one case it is 6,000, and in another 8,000 tons per acre.

Northumberland, Cumberland, and Durham produce about 90,000 tons per annum. The iron-works are increasing in importance, the cost of fuel being so low, as to admit of ores being brought from many different localities. The black-bands of Scotland and of Haydon Bridge, the brown hematites and white carbonates of Alston and Weardale, and the argillaceous ironstones of the lias of Whitby and Middlesborough, are all used in the iron-works of this district. The brown hematites are found associated in very large masses with the lead veins of this district, and they sometimes occur in distinct and regular beds. They contain from 20 to 40 per cent of iron. In some cases they exist as *riders* to the vein; in others, they form its entire thickness, which is occasionally 20, 30, and even 50 yards.

The production of iron in the Lancashire and West Cumberland district is very limited, it being confined to the Cleator works, and one or two small charcoal works in the Ulverstone district. The quality of the latter, charcoal being used as the fuel, is very superior, and the produce commands the highest prices, as it combines with the fluidity of cast iron a certain malleability, especially after careful annealing. The iron of the Cleator works is smelted with coal, and is of superior quality, although not equal to the other. The ore both of the Whitehaven and the Ulverstone and Furness districts is extensively raised for shipment to the iron-works of Yorkshire, Staffordshire, and North and South Wales. In quality these ores may be considered as the finest in the kingdom; they contain from 60 to 65 per cent. of iron. They are found both as veins traversing the beds of the mountain limestone formation, transversely to the lines of stratification, and also as beds more or less regular. The former is the general character of the Ulverstone and Furness ores; while at Whitehaven there are, at least, two beds of irregular thickness, but with clearly defined floors and roofs, and often subdivided by regular partings. These beds are occasionally 20 or 30 feet thick. They lie beneath and close to the coal measures, which both furnish the necessary fuel, and also important beds of argillaceous ironstone for admixture.

The Forest of Dean produces every year about 30,000 tons of iron. The ores are carboniferous or mountain limestone ores lying beneath the coal measures, which are not here productive of argillaceous ironstones, as in the other principal coal-fields of the kingdom. There is also a bed of ore in the millstone-grit measures. The limestone ore is arranged rather in a series of chambers than in a regular bed. These chambers are in some places of great extent, and contain many thousand tons of ore, which is generally raised at low cost, no timbering or supports for the roof being required. The iron made from this ore is of a red short nature, and is especially celebrated for the manufacture of tin plates. It commands a high price, and is extensively shipped to South Wales. It yields from 30 to 40 per cent of iron.

The micaceous iron ores, and the magnetic oxides of Dartmoor, &c., are only just beginning to be known. They produce a superior iron, adapted to the manufacture of the finest steel.

In the Island of Anglesea, Tremadoc, Carnarvon, and other localities round the North Welsh coast, are ores of inferior quality, but lying in large masses; they can be raised at trifling expense.

In some parts of Somersetshire, Gloucestershire, &c. hematitic conglomerates are found at the base of the new red sandstone. Their character as workable ores is very variable, being mixed up with

so much extraneous material as to be almost worthless; but in some cases they exist in regular beds, and contain so large a portion of hematite as to be of importance.

The clay ironstones of the lias are only just beginning to be added to our iron-making resources. They furnish an example of the unexpected development of natural wealth, arising from the facilities afforded by railroads. Ironstone is raised at a cheap rate along the outcrop of the beds, on the coast from Whitby to Scarborough. An important bed has lately been opened at Middlesborough. Mr. Blackwell has recently shown the vast extent and importance of the silicious ironstone from the oolite near Northampton.

The greensand of Sussex, which, in consequence of the exhaustion of our forests, has long ceased to yield ironstone to our furnaces, may, in consequence of the facilities of transit offered by railroads, again be called upon to yield supplies of this important ore. Scotland in the year 1851 produced 775,000 tons of iron.[1]

Section IV.—Preparation of the Ore and Fuel for Smelting.

Iron ores are not sufficiently valuable to allow of the crushing, stamping, washing, and other processes which precede the reduction of copper, tin, and other ores. They are usually roasted for the purpose of expelling water and carbonic acid, and producing that porous condition which is favourable to the smelting process. The argillaceous carbonate, or clay ironstone of the coal measures, which, as already stated, is the chief source of the iron of this country, and produces from 30 to 33 per cent. of pig iron, loses by roasting from 25 to 30 parts in every 100. The loss consists chiefly of water and carbonic acid.

The usual method of roasting the ironstone is in heaps, for which purpose a piece of ground is levelled and covered with a layer of coal, from 6 to 8 inches thick. The pieces of ironstone, as near the same size as possible, are arranged upon this, to the height of about 2 feet. This surface is levelled by introducing small pieces of ironstone in the spaces left by the larger pieces. Upon this small coals are cast in a layer of about 2 inches. Ironstone is then piled up so as to form a wedge-shaped heap, and the hole is lastly covered with small coal. The usual height of such a heap is 6 or 7 feet, and its breadth at the bottom from 15 to 20 feet. The pile is lighted by applying coals to the ground stratum at the windward end, and after having burned to a certain distance, the pile is prolonged in the opposite direction. The fire creeps slowly along, gradually igniting the whole heap from the bottom to the top. When the coals are all burnt out, the pile gradually cools, and in about a month from the commencement of the operation the ore is fit for the furnace.

The roasting of the ore is also frequently carried on in furnaces resembling lime-kilns. In a hilly district, such as that of Colebrook Dale, they are built of the form shown in Fig. 1218, by the side of a hill, so that the mouth of the furnaces may be on

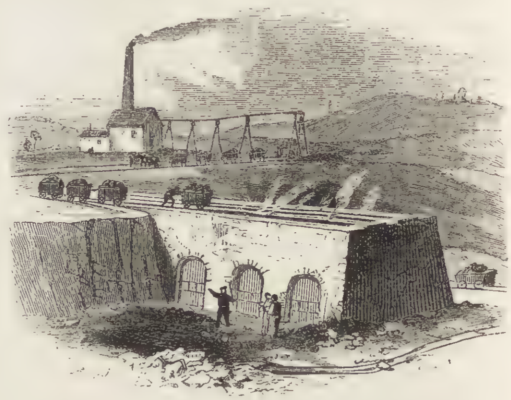


Fig. 1218. ROASTING IN KILNS. (*Colebrook Dale.*)

a level with the mouth of the pit, and the ore, as it is raised, is wheeled along a railroad, and emptied into them. The kilns are entirely filled with ironstone, except a stratum of coals at the bottom; and when sufficiently roasted the register is closed, and the whole allowed to cool.

Black-band ironstone contains a considerable proportion of bitumen, in which case, when once ignited, it will continue to burn for a long time. Those ores which do not contain any combustible matter require during the roasting a small addition of coal dust. Hence the proportion of coal required for calcining clay ironstone varies from 5 to 20 per cent, depending on the proportion of bituminous matter.

The coal used in the reduction of the ore is, to a great extent, *coked.* This operation is performed upon a flat oblong or circular surface, called a *hearth,* which is prepared by beating and puddling over with clay. The coal is arranged on the hearth in pieces, regularly inclining to each other, each piece being placed on its sharpest angle, so that as small a

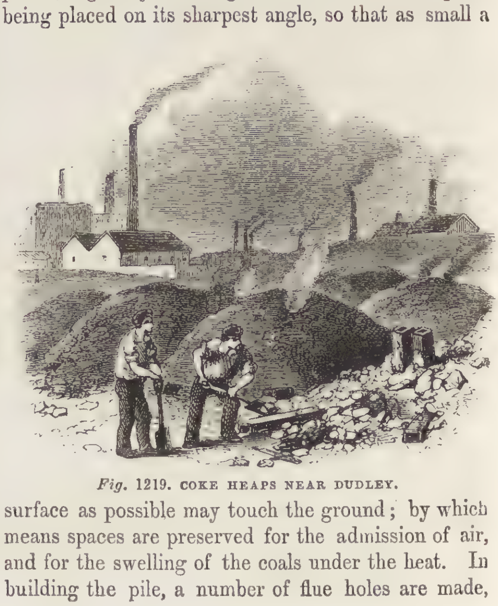


Fig. 1219. COKE HEAPS NEAR DUDLEY.

surface as possible may touch the ground; by which means spaces are preserved for the admission of air, and for the swelling of the coals under the heat. In building the pile, a number of flue holes are made,

(1) The methods of conducting the assay and analysis of iron ores are clearly stated in Mr. Phillips's Manual of Metallurgy.

extending along the ground, and terminating in vertical shafts in the centre. The heap is ignited by putting burning fuel into these vents, which are then stopped by small pieces of coal, to prevent the fire from ascending, and to cause it to creep along the bottom, where the draught is freest. When the fires of the different vents meet, the combustion gradually rises and bursts forth on all sides. Soon after the smoke has ceased, the fire is covered up with the dust and ashes of former burnings, beginning at the base and gradually heaping it up to the top. From 40 to 100 tons of coal are coked in one hearth. The time for coking depends upon the quality of the coal and the state of the weather. The combustion of the volatile matters may be complete, and the heap be covered over, in from 50 to 70 hours, but it will not be cool enough for drawing under 12 or 14 days. Mr. Mushet found the loss of weight in coking to be as follows:—

2,240 lbs.	Yield of coke.	Loss.
of free coals	700 lbs.	1,540 lbs.
of splint and free coal mixed	840 ,,	1,400 ,,
of splint slightly mixed	1,000 ,,	1,240 ,,
of pure splint	1,100 ,,	1,140 ,,

It is calculated that in Staffordshire from $3\frac{1}{2}$ to 4 tons of coal, including that employed for roasting the ore, are required for the production of 1 ton of cast iron. In Wales, where the coal produces a larger per-centage of coke, 3 tons of coal suffice for the manufacture of 1 ton of iron.

Section V.—Theory and Practice of Iron-smelting.

It has been already stated that oxide of iron is easily reduced, if a stream of hydrogen be passed over it at a red heat. A stream of carbonic oxide would be equally efficacious. But the reduction of these oxides, however easy in theory, is difficult in practice, because the particles of iron, as they are reduced, become so intimately mixed with the gangue, that they cannot combine or weld together. If the gangue were fusible at a moderate heat, it would be sufficient to raise the ore to the temperature at which the stony matters fuse, and then subject the metallic sponge thus formed to the blows of a heavy hammer, or to the compressing force of powerful rollers. The particles of iron would coalesce, and the gangue be squeezed out in the form of scoriæ or slag. If, however, the gangue were refractory, it would only fuse at the temperature at which the iron in contact with the fuel became converted into *cast* instead of *malleable* iron, which would otherwise be obtained. The ordinary gangue of iron is clay or quartz, two substances infusible by the heat of a blast furnace. In order to determine their fusion, two methods are adopted. If the ore be very rich, and it be required to produce malleable iron from it by a direct method, the ore is heated in contact with carbon: the gangue combines with a portion of the oxide of iron, forming a very fusible double silicate of alumina, and protoxide of iron; while the other portion of the iron is reduced, and all that is necessary is to pass the spongy mass under a hammer to expel the slag, and bring about the aggregation of the particles. But in this operation a portion of the oxide of iron is lost varying in amount with that of the gangue. This *Catalan* process, as it is called, produces an excellent iron, well adapted to the making of steel; it is still adopted in some places where wood is abundant for making charcoal, as in the Pyrenees, in Corsica, and some parts of Spain; but unless the ore be a very rich one, this process, wasteful alike of fuel and of ore, cannot be adopted. In the poorer ores, where the object is to extract as much of the iron as possible, the silicate of alumina must be rendered fusible by giving it some other base than oxide of iron, and for this purpose the most economical is lime. But since the double silicate of alumina and lime is much less fusible than the silicate of alumina and iron, a very elevated temperature must be employed; the iron combines with carbon, and forms crude or cast iron, which is found in a state of fusion below the fused silicate or slag. By this method, which is essentially the *English* one, nearly all the iron at present manufactured is produced. The iron ore, with a proper proportion of carbonate of lime as the flux, and coke or coal as the fuel, is raised to a very high temperature in an apparatus called a *blast furnace*, a section of which is represented in Fig. 1220, while Fig. 1227, will convey a very good idea of its external appearance.

The blast furnace consists of two truncated cones A, B, united at their bases. The upper part, called the *cone* or *body*, is formed by an interior lining or *shirt* of

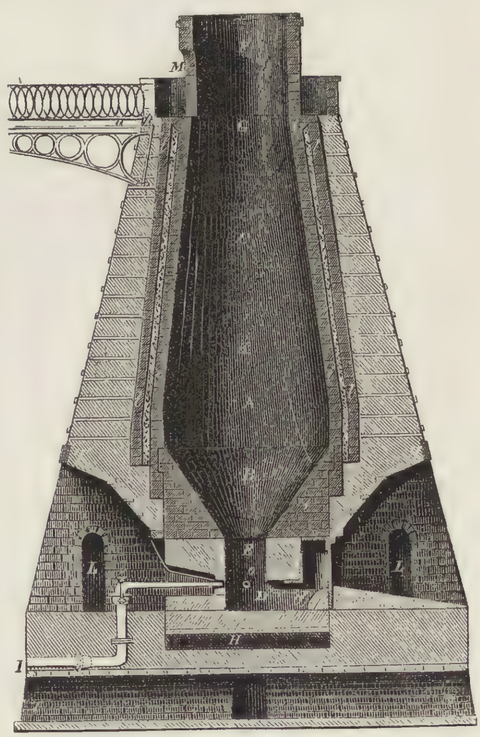


Fig. 1220. SECTION OF BLAST FURNACE.

fire-bricks *i i*: *l l* is another lining of fire-bricks, the space between the two being filled up with broken

scoriæ or refractory sand. The outer casing of fire bricks *ll*, is supported by a thick wall of masonry or brick, and this is strongly bound on the outside by stout iron bands connected by long vertical bars, whereby great strength and solidity is given to the building. The exterior casing is also traversed by numerous small channels, to allow of the escape of moisture from the masonry or brick-work, since any pent-up steam might lead to the destruction of the furnace. At the top of the furnace is an opening G, called the *throat* or *tunnel-hole*, and above this is the chimney F, in which are openings, which, with the throat, are used for pouring in the charge of fuel, ore and flux. The lower cone B, called the *boshes*, is formed of fire-brick or fire-stone, and requires the greatest care in its construction, for upon its durability depends the continued operation of the furnace. To prevent the formation of an acute angle at the junction of the two cones, forming the body of the boshes, the edges are slightly rounded off by the introduction of a narrow belt, whereby a space is formed called the *belly*. The lowest division E, called the *hearth*, is nearly quadrangular in form: it is constructed with large slabs of refractory sandstone cemented with fire-clay. It is somewhat smaller at the bottom than at the point where it meets the boshes, and its angles are gradually rounded off. The bottom of the furnace is formed of a large fire-stone, supported by a mass of masonry in which are various channels H, left open for the escape of moisture from the brickwork; and to keep the whole structure dry; the foundations are traversed by two large arched vaults V, V, which intersect each other just below the axis of the furnace. Three of the sides of the hearth are continued down to the large fire-stone: the fourth side, D, is carried down to a certain distance, where it is supported by strong cast-iron bearers let into the masonry of the walls, which also support a heavy block of sand-stone called the *tymp*. Below this, at a distance of 5 or 6 inches and a little in advance of it, is the *dam-stone*, *d*, prismatic in form, secured on its outer side by a piece

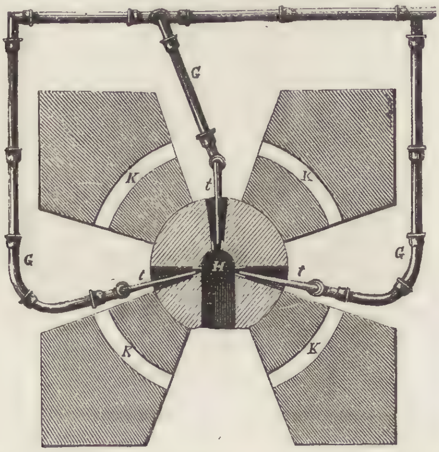


Fig. 1221. HORIZONTAL SECTION, SHOWING THE TUYERES.

of cast iron called the *dam-plate*. The part of the furnace below the tymp is called the *crucible;* and in it is collected the fused metal reduced by the operations of the furnace. The three continuous faces of the hearth are perforated a little above the level of the tymp with holes *o o*, for receiving the nozzles of tuyeres, which convey the blast from the blowing machine to the furnace. The vaulted galleries L L (corresponding to K K in Fig. 1221), allow the workmen to pass from one tuyere to another without loss of time.

Fig. 1221, is a horizontal section of the furnace at the height of the tuyeres *t*, showing also their arrangement and that of the pipes G which connect them with the blowing-machine. Each pipe is furnished with a valve worked by a screw on the outside, by which the quantity of air admitted into the furnace is regulated. The tuyeres, which are built into the hearth, are conical tubes of cast-iron, and to prevent them from being melted by the intense heat of the furnace they are made hollow, and a current of cold water allowed to circulate through them in the direction of the arrows, Fig. 1222, one pipe bringing the cold water and the other discharging it after it has been

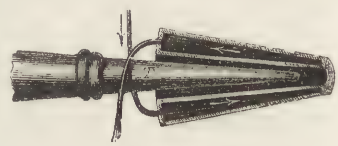


Fig. 1222.

heated. Within these tuyeres are placed the nozzles of the blast pipes; and it will be seen by reference to Fig. 1221, that by setting the tuyeres not opposite each other but somewhat inclined, the blasts do not meet each other, but each one operates upon a different part of the hearth H.

The blowing-machine in common use is shown in section in Fig. 1223. It consists of a large cylinder of cast-iron A, furnished with a piston P, fitting air-tight, the piston rod R passing through a stuffing-box at the top, and usually connected by a parallel adjustment to the oscillating beam of a steam engine.

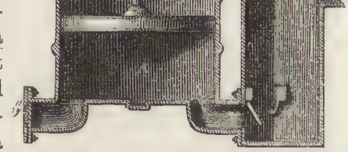


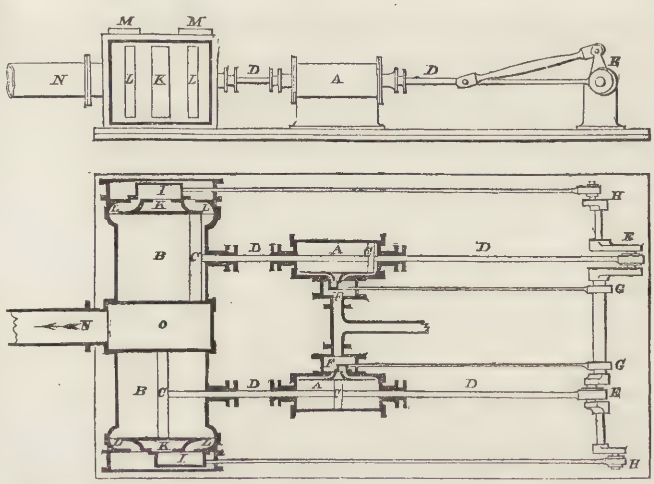
Fig. 1223. SECTION OF BLOWING MACHINE.

The cylinder is closed at the two extremities, but there are two lateral openings v v''' communicating with the outer air, and two other openings v' v'' communicating with a side chamber B, also of cast-iron. The operation of this machine is as follows:—Supposing the piston to be descending from the top to the bottom of the cylinder, it will condense the air below it; this will force open the valve v' and escape into the chamber B. By this act the valve v''' will be more firmly closed, since it is so hung that it can only open from without inwards. While this operation is proceeding, the air above the piston being greatly rarefied,

the denser air on the outside forces open the valve v, and rushes in; the valve v'' cannot open during this act, because it is hung so as to open only from A into B, not from B into A. Supposing the piston to have arrived at the bottom of the cylinder and to be ascending, the air above it becomes condensed and passes through v'', into B, while v becomes firmly closed; at the same time fresh air rushes in below the piston through v''', and v' is closed. From B, the air passes through o, to the pipes G G, Fig. 1221, and the use of the chamber B is, to allow the air to equalize itself so that it may proceed through o in a stream of tolerably equal density. It is not unusual for each blowing machine to be provided with two cylinders, which act alternately at each stroke made by the beam of the steam engine by which it is worked. Some of the large Welsh furnaces[1] consume on an average 3,600 cubic feet of air per minute, or about *nine tons weight of air per hour.* The pressure at which the air is sent into the hearth varies with the nature of the fuel and the season of the year. When the air is rarefied by the heat of summer, the blowing-machine must be exerted more than in winter, in order to supply the furnace with the same amount of oxygen. Less pressure is required with a light and easily combustible fuel, such as charcoal, than with a dense coke. In the former case the pressure may not exceed ½ lb. on the square inch; in the latter, the average is about 2½ or 3 lbs.

The objection to this form of blowing-engine is its great size, and the small velocity with which the air is driven, this being no higher than that of water passing through an ordinary pump. When the engine is not driven by water power, but by steam, there is no reason why as great a velocity should not be imparted to it, as a high-pressure locomotive power is capable of supplying. With these views Mr. Archibald Slate of Dudley has contrived a blowing engine, the construction of which will be understood by referring to Figs. 1224, 1225, which represent an elevation and plan thereof. A A, are the steam cylinders, each 10 inches in diameter and with 2 feet stroke, and B B the blowing cylinders, 30 inches in diameter and 2 feet stroke, with their pistons C fixed on the same piston rods D, which are connected to two cranks E, fixed at right angles to each other on the same shaft. The slide valves F of the steam cylinders are worked by the eccentrics G, on the cranked shaft, and the cranks H, at the outer ends of the same shaft, work the slide valves I of the blowing cylinders.

(1) The dimensions of the great blowing cylinder at one of the largest of the Welsh iron works are as follows:—diameter 9 feet 4 inches, height 8 feet 4 inches. The piston has a range of 8 feet, and makes 13 strokes in a minute. Allowing 4 per cent. for loss by leakage, we have 12,588 cubic feet of air expelled per minute.



Figs. 1224, 1225. ELEVATION AND PLAN OF SLATE'S HIGH PRESSURE BLOWING ENGINE.

The centre port K passes downwards to an external opening for the admission of the air, and the discharge ports L L, deliver into the passages M, on the top of the cylinder, which communicate with the air main N, by the chest O, formed between the cylinders. The piston of the blowing engine is made without any packing, it being a light hollow cast-iron piston turned to an easy fit. The slide valve of the blowing cylinder has a packing plate at the back, working against the cover of the valve box, with a ring of india-rubber inserted between this plate and the back of the valve, to give a little elasticity. Such an engine is capable of supplying air to a blast furnace which makes 160 tons of iron per week, with a surplus blast for a cupola or refinery. Such an engine, with the piston moving with a speed of 640 feet per minute, is capable of supplying nearly 30 circular inches of tuyere at a pressure of 3½ lbs. to the square inch.[2]

The dimensions of the blast-furnace vary with the kind of ore to be smelted. Some are only 36 feet high including the chimney; others are about double that height; but the usual height is from 45 to 50 feet without the chimney, which is 8 or 10 feet more. In such a furnace the crucible will be about 6½ feet high, and 2½ feet square at the top; the boshes 8

(2) The speed of a locomotive piston at 40 miles per hour is about 800 feet per minute. In 1850, Mr. Slate erected at the Woodside Iron Works, near Dudley, a 40-inch blowing cylinder, worked by a steam engine with a cylinder 14 inches in diameter. The stroke was 2 feet, the boiler 27 feet long and 4 feet diameter. On the outlet pipe were placed 4 tuyeres, 2 of them 2½ inches, the others 2 inches diameter. The engine being run up to its full velocity, reached 145 strokes per minute, at which rate the density of the air issuing from the 4 tuyeres was nearly 5 lbs. per inch; but the engine was perfectly noiseless and steady on account of the great regularity of the blast. With an adjusting expansive valve fitted to this apparatus, its full complement of blast was thrown into one furnace, viz. 3,500 cubic feet of air per minute: the pressure of the air in the main close upon the engine was a little over 3 lbs. to the inch; at the tuyeres on the furnace it was rather under; the loss being due to friction and leakage on account of the tortuous character and length of the main, which exceeded 300 feet.

feet high, and 12 feet in diameter at the top; the cavity of the furnace is about 30 feet high; the chimney 8 feet high, and widened to 16 feet to allow the charge to be easily tossed in. The form of furnace shown in Fig.1220 is adapted to the hot-blast, cold-blast furnaces being narrower at the top. Some of the largest furnaces are in South Wales, in which the diameter at the boshes, or widest part, is from 15 to 18 feet. These have a capacity of 7,000 cubic feet, and contain at least 150 tons of ignited materials.

Much care is required in raising a new furnace to the temperature necessary for the smelting of iron. A temporary fire-place is first erected at the lower part, to which the whole cavity of the furnace is made to act as a chimney, so that when the fire is lighted, the draught is violent, and much heat is carried up. The fire is kept burning for about three weeks, at the end of which time the furnace is sufficiently dry to receive a charge of coke. The temporary fire-place is then removed, and other preparations are made for the purpose. A quantity of ignited coke is thrown in, and this is gradually increased until the whole cavity is filled. The quantity required by a furnace of the average size is about 99,000 lbs., the splint coal for which would weigh 198,000 lbs. When the furnace has been sufficiently heated by coke, proportionate charges of coke, ironstone, and blast-furnace cinders are added. At first the ironstone bears only a small proportion to the weight of the coke, but is afterwards increased to the full burden. The filling is continued regularly, and when the top of the furnace has acquired a considerable degree of heat, the blast is introduced. Before admitting the blast, the dam-stone and dam-plate are laid. On the top of the plate is a slight depression, curved outwards, to allow the slag to flow off in a connected stream, as it tends to surmount the level of the dam. From the dam-plate to the level of the floor, a declivity of brick-work is erected, down which the slag flows. The fauld is stopped up with sand, and the furnace bottom covered with powdered lime or charcoal dust. Ignited coke is then allowed to fall down, and is brought forward with iron bars nearly to a level with the dam. The tuyere holes are opened, and lined with a soft mixture of fine clay and loam. The blast is first introduced through a small discharge-pipe, and afterwards a larger one is used. In about 2 hours after blowing, a considerable quantity of lava will be accumulated; this is admitted to all parts of the hearth, and glazes the surfaces of the fire-stone. It then rises to a level with the notch in the dam-plate, and flows over. When the metal has risen nearly to a level with the dam, it is let out by cutting away the hardened loam of the fauld, and conveyed by a channel made in the sand in front of the furnace, to the place where it is cast into pigs, as will be noticed more particularly hereafter. In 6 days from the commencement of blowing, the furnace will have wrought itself clear, at which time the charge will be in the following proportions:—400 lbs. of coke, 336 lbs. of clay ironstone, and 100 lbs. of limestone. This charge is thrown into the furnace every hour. In the hilly district of Colebrook Dale, the blast-furnaces are built by the side of a hill, on the summit of which the charge is prepared, and tossed

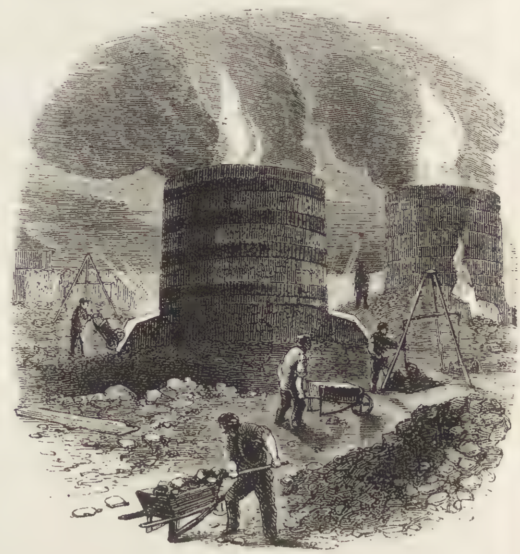


Fig. 1226. MOUTHS OF BLAST-FURNACES. (*Colebrook Dale.*)

into the furnace mouth, as shown in Fig. 1226. Near Dudley the charge is in some cases moved by steam power up an inclined plane, as represented in Fig. 1227; in other cases a mechanical lift is employed.

The action of these three substances upon each other, leading to the production of a vitreous slag, and metallic iron, has already been stated. The

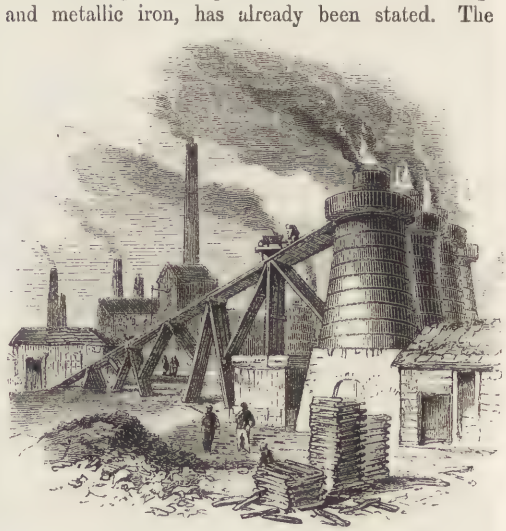


Fig. 1227. BLAST-FURNACES NEAR DUDLEY.

chemical changes by which these apparently simple results are brought about, are somewhat complicated. The charge having been thrown in at the top of the furnace, gradually descends until it reaches the upper part of the boshes. In the cone the heat is not very great: near the boshes it is considerable, and in the hearth it is at its maximum, for here the oxygen of the blast meets the fuel, and produces the

most vivid combustion. At about the middle of the boshes, the heat is much dimmished, for the oxygen having been converted into carbonic acid, this gas and the nitrogen of the air of the blast part with a portion of their heat to the fuel and the mineral at the lower part of the cone. Here the carbonic acid, in contact with the heated fuel, combines with an equivalent of carbon, and becomes converted into carbonic oxide, with a great expansion of volume, and consequently a great absorption of heat, so that while the boshes are at a white heat, the base of the cone is only at a red. As the carbonic oxide, at a high temperature, comes in contact with the oxide of iron, it reduces it to a metallic state, and becomes converted into carbonic acid. This acid gas is also formed by the conversion of the limestone into caustic lime, so that the gases which escape by the throat of the furnace consist of nitrogen, carbonic oxide, and carbonic acid. There is also a portion of hydrogen and carburetted hydrogen, arising from the dry distillation of the fuel in the upper part of the cone, for the coal is never so thoroughly coked as to have parted with all its gases. A certain amount of moisture enters by the tuyeres, and its decomposition increases the quantity of carbonic oxide and hydrogen. Hence it will be seen that a vast amount of inflammable gaseous matter must be constantly pouring from the blast-furnace all the time that it is in action, producing a great body of flame and smoke by night, and lighting up the country for miles around.

The chemical changes which go on in different parts of the furnace, have been tested by collecting the gases at various distances below the throat or tunnel-hole, by passing a wrought-iron pipe to the depth at which it was required to examine the products of combustion. To the upper extremity of this tube was connected a leaden pipe, by which the gases were conducted to a place suited for their analysis. Near the throat of the furnace, the hygroscopic water is driven off from the charge. When it has sunk to the distance of 10 or 12 feet from the surface, the combined water of the hydrated oxide of iron begins to be expelled, and a little lower down, the carbonic acid, both of the ore and of the flux, is partly set free, and a portion of the oxide of iron becomes reduced to the metallic state. In the lower part of the cone, and at the commencement of the boshes, the reduction is completed, and the rest of the carbonic acid liberated. At the lower part of the boshes, where the temperature is very high, the lime of the flux and the ash of the fuel combine with the silica to form various double silicates, which afterwards form a fusible slag. Here also the iron is exposed in a slightly oxidising atmosphere to a very high temperature in the presence of carbon, a portion of which substance combining with the metal, converts it into *cast-iron*. The presence of the iron and the carbon also serves to reduce a portion of the silica, the silicium combines with the iron, and the oxygen of the silica with the carbon. When the charge thus modified arrives at the upper part of the hearth, the intense heat, caused by the action of the blast upon what remains of the fuel, completely fuses both the iron and the silicates, and they pour down into the crucible beneath. The construction of the hearth allows the melted products to fall rapidly through the blast, and this is quite necessary, for the oxidising influence of the vast body of air poured into this part of the furnace is such, that it would speedily convert the reduced metal to an oxide, which would be rapidly absorbed by the slag, and thus occasion great loss. But on reaching the crucible, the fused products arrange themselves in the order of their density. The iron occupying the lowest part, and being covered by the silicates, is completely protected from all oxidising influence. The silicates or slag occupy a volume five or six times greater than that of the iron, so that as it rises to the level of the dam-plate, it flows over, and passes down the inclined plane to the ground, and when cold is removed by means of pointed iron levers. At some works the slag is made to flow into iron waggons, whereby it is moulded into large blocks. These waggons run on a railway, so as to admit of being easily wheeled off. The iron slowly accumulates in the crucible, and in the course of 8, 12 or more hours, according to the construction of the furnace, the furnace is *tapped*, and the liquid metal drawn off. For this purpose the plug of refractory clay, which closes a hole in the bottom of the crucible, is pierced with a long bar. But before tapping, the men prepare for the reception of the liquid metal a number of moulds in the sand which composes the

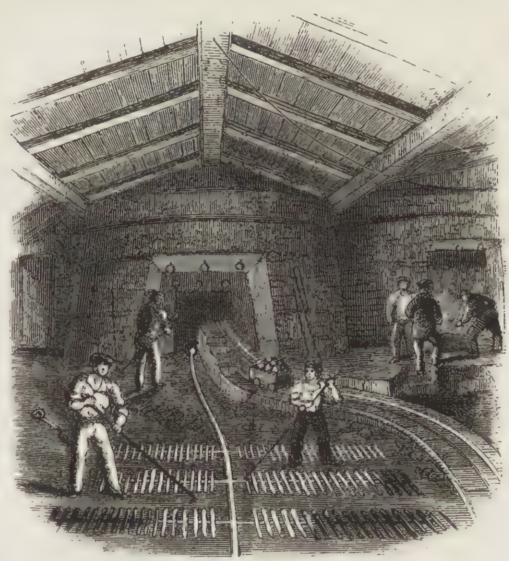


Fig. 1228. CASTING PIG-IRON.

floor of the workshop. For this purpose blocks of wood are buried, which on being taken up leave a number of parallel trenches. These are connected by a channel at right angles to them, and communicate with the hole at the bottom of the crucible. The blast is then shut off, the plug of clay removed, and the molten stream flows out sparkling and bright, the light and heat becoming more and more intense as it rolls on and increases in volume. In order to

make the metal flow regularly into the side channels, it is necessary here and there to interrupt the progress of the stream by a long piece of wood, as the metal does not continue sufficiently fluid to fill them up equally without this precaution. The moulds form the metal into semi-cylindrical bars called *pigs*, united by one of larger dimensions called a *sow*, the moulds being so arranged as to make the points of connexion very thin between the pigs and the sow, so that the pigs are easily broken off when the casting is cold. When the crucible is emptied, the clay plug is restored, the blast is put on, and the operations of the furnace proceed as before, day and night, weekday and holiday, for years together;[1] for it is absolutely necessary to keep up the heat of the furnace, and this can only be done by keeping it at work; for should it once cool down, this huge and costly piece of apparatus would be ruined.

The quality of pig-iron produced in an ordinary blast-furnace from clay iron-stone, and with coke as the fuel, is subject to considerable irregularity; but the experience of years has enabled the skilful iron master to classify the irregularities, so to speak, into marketable products. Six different kinds of pig-iron are distinguished. The first three, named No. 1, No. 2, and No. 3, are considered as *foundry metal;* they contain carbon in different degrees, but all of them in a higher degree than those selected for making bar or malleable iron. No. 1 is saturated with carbon, the effect of which is to produce a soft iron, very fluid when melted, so that it will adapt itself perfectly to the shape of the mould, and is hence used for small and ornamental castings. It is also so soft as to yield readily to the chisel. No. 2 contains less carbon than No. 1: it is not so soft when cold, nor so fluid when melted; but being harder and stronger, is preferred for those parts of machinery which require strength and durability. The quantity of carbon contained in these two sorts renders them unfit for being manufactured into bars; but No. 3, or *dark-grey iron*, containing less carbon than No. 1 or No. 2, can be used either for the forge or for the foundry. It is employed in heavy castings, such as tram plates, heavy shafts, wheels, cylinders of steam-engines, &c. The next quality is called *bright* iron, from its being of a lighter colour and of a brighter lustre than the foregoing varieties. It is used for large castings, but is not sufficiently fluid for fine work. A fifth variety is *mottled* iron, the fracture of which is mottled with grey and white. It is too thick and brittle for the foundry, and its use is confined to the forge. The last variety is called *white* iron, from its silvery white colour. It is quite unfit for casting on account of its thickness and extreme brittleness. It contains a smaller proportion of carbon than any other sort of pig iron; indeed its production often depends upon a deficiency of fuel in the charge.

The different kinds of iron present different phenomena in flowing out of the furnace. They have been well described by Mr. Mushet. "When fine, (No. 1.) or super-carbonated crude iron is run from the furnace, the stream of metal, as it issues from the fauld, throws off an infinite number of brilliant sparkles of carbon. The surface is covered with a fluid pellicle of carburet of iron, which, as it flows, rears itself up in the most delicate folds. At first the fluid metal appears like a dense ponderous stream, but as the collateral moulds become filled, it exhibits a general rapid motion from the surface of the pigs to the centre of many points; millions of the finest undulations move upon each mould, displaying the greatest nicety and rapidity of movement, conjoined with an uncommonly beautiful variegation of colour, which language is inadequate justly to describe. Such metal in quantity will remain fluid for twenty minutes after it is run from the furnace, and when cold will have its surface covered with the beautiful carburet of iron already mentioned, of an uncommonly rich and brilliant appearance."

Very different are the phenomena presented by the inferior iron, No. 4. From all parts of the fluid surface is thrown off a vast number of metallic sparks, arising from a cause different to that exerted in the former instance. The absence of carbon renders the metal liable to the oxidising influence of the atmospheric air. Small spherules of iron are ejected from all parts of the surface, to the height of 2 or 3 feet, when they inflame, and separate with a slight hissing explosion into a great many particles of brilliant fire, forming oxide of iron. "The surface of oxygenated iron, when running, is covered with waving flakes of an obscure smoky flame, accompanied with a hissing noise, forming a wonderful contrast with the fine rich covering of plumbago in the other state of the metal, occasionally parting, and exhibiting the iron in a state of the greatest apparent purity, agitated in numberless minute fibres from the abundance of carbon united with the metal." As the oxygenated iron cools, its upper surface becomes covered with a scale of blue oxide, which being removed, a number of deep pits are presented. "This iron in fusion stands less convex than carbonated iron, merely because it is less susceptible of a state of extreme division; and, indeed, it seems a principle in all metallic fluids, that they are convex in proportion to the quantity of carbon with which they are saturated." The appearance of No. 2 and of No. 3 in a state of fusion, present some of the phenomena both of No. 1 and of No. 4.

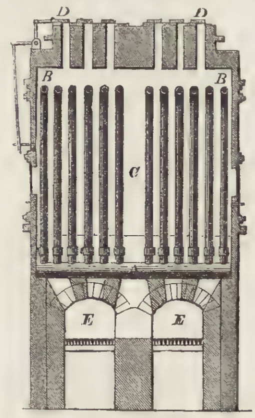
The quality of the metal can also be judged of before it is run from the furnace, by the colour and form of the scoriæ, the colour of the crust upon the working bars, and the quantity of carburet attached to it. That cinder which indicates the presence of carbonated iron in the hearth of the furnace, forms itself into circular compact streams, which become

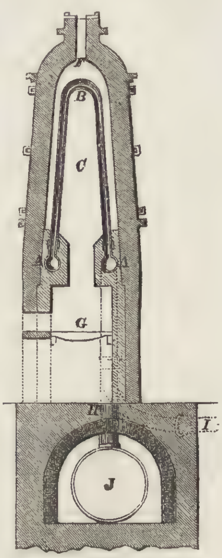
(1) A well-constructed furnace will work four or five years without requiring repair, and then only the refractory lining will have to be reconstructed. Some of the Welsh furnaces have been worked for more than ten years without requiring any extensive repairs, and at the end of that time, only the lower portions of the lining have required reconstruction; the upper part of the cone being exposed to only a moderate temperature, has been known to last for nearly forty years.

consolidated and inserted into each other: these are from 3 to 9 feet in length. "Their colour, when the iron approaches the first quality, is a beautiful variegation of white and blue enamel, forming a wild profusion of the elements of every known figure. The blues are lighter or darker, according to the quantity of the metal, and the action of the external air while cooling. When the quality of the pig-iron is sparingly carbonated, the blue colour is less vivid, less delicate, and the external surface rougher and more sullied with a mixture of colour." The furnace-cinder when No. 3 iron is produced, assumes a long zigzag form. "Its tenacity is so great, that if while fluid a small iron hook be inserted into it at a certain degree of heat, and then drawn from it with a quick but steady motion, 20 or 30 yards of fine glass thread may be formed with ease. When by accident a quantity of this lava runs back upon the discharging-pipe, it is upon the return of the blast impelled with such velocity as to be blown into minute delicate fibres, smaller than the most ductile wire. At first they float upon the air like wool, and when at rest very much resemble that substance." The cinder frequently crystallizes in cooling: cellular masses form among it, which on being opened, are sometimes found full of perfectly crystallized forms.

The Hot-Blast.—The enormous quantity of air injected into a blast furnace to promote the combustion of the fuel, must have its own temperature raised before its oxygen can combine with the carbon of the fuel in the way of combustion. In fact one portion of the heat of the furnace is expended in raising the air to the temperature necessary for the combustion of the remaining fuel: a second portion of the heat is carried off by the nitrogen of the injected air, and by the volatilized products; while a third portion is employed by the ore and the flux; so that not only is there a wasteful expenditure of heat, but the very means employed to raise the temperature of the furnace, has the effect of keeping down the temperature. If, however, the temperature of the air be raised to about 600° before it is injected into the furnace, a much higher temperature can be obtained with the same charge of fuel, or the same temperature with a diminished charge of fuel. It has been calculated that by the use of the blast at 572° instead of 60°, a furnace may have its temperature raised one-eighth; and supposing the temperature obtained by working with cold air to average 2,700°, the hot-blast will raise it to 3,060°, making a difference of 360° in the effective heat of the furnace. Hence many substances infusible in a cold-blast furnace, become fusible in a hot. Coal can be used in the hot-blast furnace instead of, or mixed with coke; less fuel and less limestone flux are required; and ores previously unfitted for the manufacture of foundry iron can be smelted.

Figs. 1229, 1230, are vertical and lateral sections of the apparatus for heating the air which supplies the blast. It consists of a kind of stove, in which the air is made to pass through a series of cast-iron pipes before arriving at the nozzles by which it is injected into the furnace. A A is the wall of the furnace, B a section of one of the syphon-shaped tubes, arranged as in Fig. 1230, from 6 to 8 inches in diameter. These are connected by sockets and iron joints to horizontal pipes A of much greater diameter. E is the fire-place for heating the pipes, which are surrounded by





Figs. 1229, 1230. SECTIONS OF HOT-BLAST APPARATUS.

a large hot-air chamber, into which the gases from the fire-place escape by the openings D D at the crown of the arched covering F. The draught is regulated by a damper placed over the top by which the openings can be more or less closed by moving a compound lever. The large cylinder J, Fig. 1230, communicates with the cylinder by which the blast is supplied, and is large enough to neutralize the vibrations occasioned by the oscillation of the piston by which air is forced into the furnace. The horizontal connecting-pipe A, through which the cold air enters the stove, is furnished with a stop or diaphragm in the middle, and the air, in order to escape by the pipe on the opposite side, must traverse the syphon-pipes B, the heat of which raises the temperature of the blast to the proper point. In most cases each tuyere is provided with a heating apparatus; and in a furnace producing 60 tons of cast-iron per week, from 30 to 35 tons of coal will be required in that time for raising the blast to the temperature of 600°.

It has been proposed to employ the highly-heated gases which escape from the throat of the furnace, for the purpose of heating the blast with which it is supplied. When it is considered that one of the large Scotch furnaces yields from 150 to 200 tons of iron per week, with a consumption of from 300 to 400 tons of coal, and that from 4,000 to 5,000 cubic feet of air per minute is injected into it, we may form some idea of the enormous waste of heat in the volumes of smoke and flame which are being constantly discharged from its chimney. Many methods of applying this waste heat to the heating of the blast have been proposed, but most of them have been objectionable on account of the difficulty of repairing the apparatus without blowing out the

furnace. The least objectionable method is that by Mr. Budd, as employed at the Ystalyfera iron works in South Wales. The heating ovens are arranged so as to be quite distinct from the furnace, so that they can be repaired without interfering therewith. The stoves are built in the masonry a little below the throat of the furnace, and a chimney, 25 feet higher than the top of the platform, affords the means of drawing into them as much of the hot air and flame as may be required. This arrangement will be understood from Fig. 1231, in which *a* is the furnace, *b* a series of flues situated about 3 feet from the top for conveying the hot air into the chamber *c*, Fig. 1232, in which are placed the arched pipes *d*, heated by the gases from the furnace. The heat of the stove is regulated by the chimney *e* and its damper *f*. The cross-

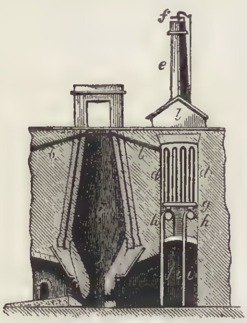


Fig. 1231.

Fig. 1232.

pipes *g* connect together the upright air-tubes *d*, and the side pipes *h* convey the blast which arrives by the upcast mains *i*, to the various cross-pipes. The heated air is afterwards conveyed to the tuyeres by the downcast pipes *j l*. There is also a door *k* in the the brick-work to allow the apparatus to cool before going in to make repairs. The gases which escape from the furnace have a temperature of about 1,800°, so that it is only necessary to draw through the chamber such a supply (about one-sixth of the whole quantity has been found sufficient) as will heat the stream of air in the tubes to 600°. To do this the gases should leave the stove at 800°. If the temperature of the hot-air chamber decline, it may be raised by slightly elevating the damper *f*. At the Ystalyfera works, another portion of the waste gases is conducted through flues, and made to heat the boilers which supply the engine of the blowing machine, and there is still a large amount of heated air and flame which passes off without doing any service. The economy of fuel by these arrangements is about one-third, so that 2 tons of coal produce the same quantity of iron as was formerly produced by 3 tons.

From the results of some experiments by Messrs. Bunsen and Playfair, upon a hot-blast furnace near Alfreton, in Derbyshire, it was concluded that 81·54 per cent of the heat generated by the furnace is continually carried off by the unconsumed gases escaping from the chimney. This estimate appears to be excessive, but there is no doubt that the amount of heat thus wasted is very large. In Great Britain, where the abundance of fuel leads to its extravagant expenditure, little more has been done to apply this vast body of heat to useful purposes, than to heat the blast or the boilers of the steam-engine, as already stated. On the Continent, however, some successful attempts have been made to apply this heat not only to the above purposes, but also to the roasting of the ores, and to the refining and puddling of iron. For this purpose the gases are drawn off from the furnace, cooled and purified by being passed through water, and when ignited, they burn with a very intense heat. In some cases air-pumps are employed to propel the gases to the places where they are to be used as fuel.

The chemical changes which take place in a hot-blast furnace were examined by Messrs. Bunsen and Playfair, in 1845, in the furnace already indicated. This furnace is 40 feet high, 11 feet wide at the boshes, and is blown with air heated to 626°, under a pressure of 6.75 inches of mercury, the diameter of the nozzles being $2\frac{3}{4}$ inches. The furnace is supplied in the course of 24 hours with 80 charges, each consisting of 420 lbs. of calcined ore (clay carbonate of iron), 390 lbs. of coal, and 170 lbs. of limestone. The coal and ore are charged in large lumps: the limestone in lumps about the size of the fist. The product of each charge is stated to be 140 lbs. of pig-iron.

In order to collect the evolved gases, a wrought-iron tube was passed into the furnace to the various depths at which it was desired to examine the products of combustion; and to the upper extremity of this tube was attached a leaden pipe, by which the gases were conducted into proper vessels for analysis. At a certain depth the heat of the furnace was so great that the iron tube became fused. A small hole was therefore bored through the masonry from the front of the furnace to its internal cavity, so as to reach the hearth just beneath the boshes, at a distance of six feet from the bottom of the crucible, and two feet nine inches above the tuyeres. The gas drawn off from this opening exhaled a powerful odour of cyanogen; and in kindling it, the flame exhibited the purple tint characteristic of that substance. Analysis showed an amount of cyanogen equal to 1·34 per cent. The other results, as obtained at various depths from the top of the furnace, are exhibited in the following table, which will also show the various changes produced by the current of air during its passage from the tuyeres to the chimney:—

	Depth from the top.							
	I. 8 ft.	II. 11 ft.	III. 14 ft.	IV. 17 ft.	V. 20 ft.	VI. 23 ft.	VII. 24 ft.	VIII. 34 ft.
Nitrogen . . .	54·77	52·57	50·95	55·49	60·46	58·28	56·75	58·05
Carbonic acid .	9·42	9·41	9·10	12·43	10·83	8·19	10·08	0·00
Carbonic oxide	20·97	29·24	19·36	19·77	19·77	29·97	29·97	25·19
Light Carburetted Hydrogen . .	8·23	4·57	6·64	4·31	4·40	1·64	2·33	0·00
Hydrogen . . .	6·49	9·33	12·42	7·62	4·83	4·92	5·65	3·18
Olefiant Gas . .	0·85	0·95	1·57	1·38	0·00	0·00	0·00	0·00
Cyanogen . . .	0·00	0·00	0·00	0·00	0·00	trace	trace	1·34

It will be seen, from the production of carburetted hydrogen, that the coking of the coal goes on even to the depth of twenty-four feet. At a depth of fourteen feet, the amount of nitrogen is least; while at the same depth the amount of hydrogen and carburetted hydrogen is greatest: this, therefore, appears to be the zone of the most active distillation. It was found by analysis that 100 parts of the furnace-coal yielded a mean of ·769 sal ammoniac; and as 280 cwt. of coal were consumed in twenty-four hours, it follows that 2 cwt. of sal ammoniac might be obtained from it, as a secondary product, simply by conducting the gas, previous to its application as fuel, through a chamber containing muriatic acid. The quantities of carbonic oxide and carbonic acid have no proportional relation to each other; but it would appear, from the constant results obtained at the depth of twenty-four feet, that below this point there is a continuous liberation of carbonic acid, obtained either from the limestone flux, or caused by the reduction of the oxide of iron, or probably from both sources. Judging, however, from the average composition of the gases evolved from the materials employed, the excess of carbonic acid may be due to the flux, the reduction of the ore taking place at the boshes only. But "the most important feature of this investigation is the discovery of the presence of large quantities of cyanide of potassium in the lower region of the furnace. On introducing an iron pipe into the hole pierced in the front of the masonry above the tuyeres, large quantities of this substance were readily collected. To do this, the iron tubing, in order to prevent its being fused, was inserted to within a certain distance only of the internal cavity of the furnace; and to its outer end was attached a series of receivers, in which the various products were cooled and collected. From the quantities thus obtained from a given volume of gas, it was calculated that at least 224 lbs. of cyanide of potassium were daily generated in the furnace. When the iron tube used in this experiment was withdrawn from the hole, it was found to be internally encrusted with melted cyanide of potassium, which became deliquescent on exposure to the air." The sources of the potash were the calcined ore, which contained 0·743 of potash, and the coal, which contained 0·07 per cent. It had been shown by Mr. Fownes, "that cyanide of potassium is produced on passing a current of nitrogen gas over a mixture of charcoal and carbonate of potash, strongly heated in an iron tube; "and it consequently appears that the cyanogen present is furnished solely by the direct union of the liberated nitrogen with a portion of the carbon constituting the fuel. Since, also, potash is reduced at a high temperature in the presence of carbon, it follows that no formation of cyanide of potassium in the region immediately above the tuyeres is due to the direct union of carbon with potassium, and the nitrogen of the air. The presence of this substance in the hearth of the furnace cannot fail to effect extensive chemical changes, and influence, to a considerable extent, the reducing power of the apparatus. It has been shown that, at very elevated temperatures, this salt is volatile; and if, therefore, it reaches the part of the furnace in which the reduction of the ore is effected, its high reducing properties will necessarily come into play. By this means it must become decomposed into nitrogen, carbonic acid, and carbonate of potash, of which the two former will pass off in the form of gas, while the latter, not being volatile, is carried down by the other materials in the furnace, until it reaches the point at which it is again transformed into cyanide of potassium. In this way we can easily understand that the accumulation of cyanide of potassium may ultimately become very considerable, and capable of materially influencing the action of the apparatus. When the proportion of this salt has become increased beyond a certain amount, the excess is probably decomposed, by the action of the blast, into nitrogen and carbonic acid, which escape in the gaseous form, and into carbonate of potash, the potash of which unites with the siliceous matters present, and is carried off by the slag. It is evidently very difficult to determine the exact nature of the various chemical actions continually taking place in the different parts of an apparatus of such immense size and so highly heated as a blast furnace; but it is certain that the presence of large quantities of a material of a character so highly reducing as cyanide of potassium cannot fail to materially influence the chemical changes which are there effected. The amount of this substance is probably greater in hot blast furnaces than in those at which air at the ordinary temperature is employed; but the quantity generated even in the cold-blast furnace must to a certain degree modify the reactions before described, and contribute to the reduction of the ores."[1]

Section VI.—The Manufacture of Wrought Iron.

The cast, or pig-iron, produced by the operations which have been thus far described, is contaminated with impurities, which render it brittle, and incapable of being wrought into shape by the hammer. The impurities consist chiefly of carbon and silicium, together with small portions of sulphur and phosphorus. The carbon and silicium are got rid of by exposing the pig-iron for a considerable time to oxidizing influences, such as heat and a blast of air. The effect of this is to convert the iron into oxide of iron, which forms first on the surface, and gradually penetrates into the mass. The carbon of the iron reduces the oxide first formed, producing metallic iron and carbonic oxide gas. By a similar reaction, the silicium of the iron is converted into silicic acid, which, combining with a portion of the oxide of iron, forms a fusible silicate of iron. These actions and reactions are continued, until at length the whole

(1) Phillips's Manual of Metallurgy. The Report of the experiments by Messrs. Bunsen and Playfair was made to the British Association for the Advancement of Science in the year 1845, and is published in the 15th volume of the Reports. It is entitled "Report on the Gases evolved from Iron Furnaces, with reference to the Theory of the Smelting of Iron."

mass is converted into a spongy mass of malleable iron and fusible slag. This is subjected to the percussion of a heavy hammer, or to great pressure, whereby the silicates are pressed out. The whole of the silica of the slag is not due to the silicium of the iron: a considerable portion of it comes from the sand which adheres to the pigs in the casting; another portion may also be derived from the coke used in the refining-furnace.

The cast-iron pigs also contain small portions of sulphur and phosphorus, which must be carefully removed during the refining, as their presence would effectually destroy the valuable properties of wrought iron. The separation of these substances is, however, a matter of great difficulty, so that it is better to get rid of them previous to smelting, by a careful roasting of the ore; but if the source of sulphur be the iron pyrites of the fuel, a large dose of carbonate of lime must be added to form sulphuret of calcium, which then escapes with the slags. The phosphorus may be removed by similar means; but ores containing much phosphorus or sulphur can never be made to furnish good iron.

A furnace which supplies iron for the refinery is worked so as to produce that variety of cast-iron called *white-iron*, on account of its containing a very small proportion of carbon. For this purpose the charge of ore is large in proportion to that of the fuel; and the blast is urged at high pressure in order to determine the rapid descent of the ore. The ore ought to be of good quality.

The English method of refining pig-iron consists of two consecutive operations carried on in separate furnaces. In the first, which is called the *fining-furnace*, or the *refinery*, the metal is melted, and, after being exposed to the blast of numerous tuyeres, accumulates in the bottom of the crucible, whence it is run off into a flat mould. By this operation it loses a considerable portion of the carbon, and nearly all the silicium, becomes very hard and brittle, and its surface covered with small blisters similar to some of the varieties of steel. In this state it is called *fine metal*. It is broken up and transferred to what

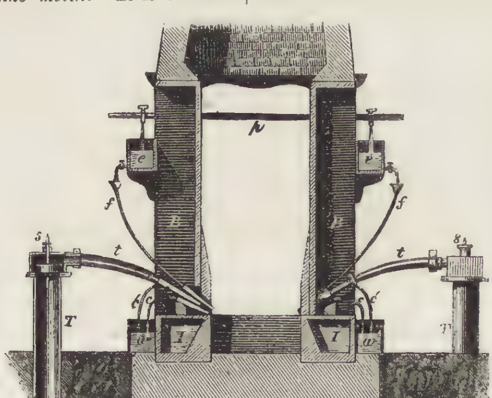


Fig. 1233. THE REFINERY.

is called a *puddling-furnace*, in which the operation of decarbonization is completed.

The refinery is usually built on a mass of brickwork, about nine feet square, and the hearth is raised only a small height above the level of the floor. The hearth H, Figs. 1233, 1234, is 2½ feet wide, and 3½ feet long. It is formed by the junction of four cast-iron troughs, I, through which a stream of cold water is made to circulate, to prevent them from being fused by the heat. The bottom of the crucible is of grit-stone or argillaceous sand, and is slightly inclined in the direction of the tapping-hole *o*. The air, which is supplied by blowing cylinders, similar to Fig. 1223, enters the hearth through the six tuyeres *t*, which are inclined at an angle of from 25° to 30°, and so arranged that the blast from each may be directed towards the face of the opposite side of the furnace, not in opposition to the opposite tuyere. The tuyeres are furnished with double casings, through which cold water is constantly running. A supply of water

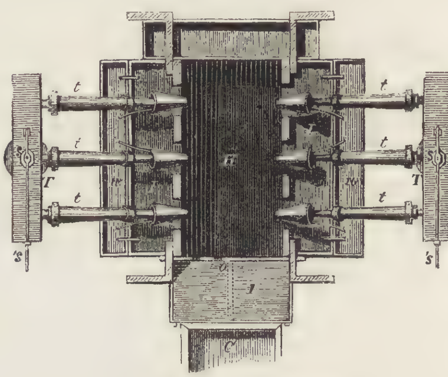
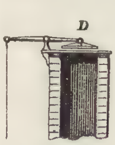


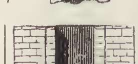
Fig. 1234. PLAN OF REFINERY.

is brought by a pipe *p* into the reservoirs *e*, whence it passes to the tuyeres, through the pipes *f*, and escapes through the tubes *c'* into the tanks *w*, into which the water from the iron troughs flows by the syphon tubes *c*. A furnace of this kind consumes about 400 cubic feet of air per minute. This is supplied by the pipes T, which are furnished with screw-valves at *s* for regulating the supply. Above the hearth is a chimney 16 to 18 feet high, supported by four cast-iron columns, so as to allow free access to the fire on all sides. The tapping-hole *o* is placed in one of the shorter sides of the hearth, and by it the melted metal and the slag flow out into the mould C, where the metal is cooled by quenching with water. The plate of fine metal thus formed is about 10 feet long, 2½ feet broad, and 2 inches thick. A thin crust of slag forms upon its surface; but the greater portion is collected in a small pit at the lower end of the mould. As soon as one charge of metal is run out, the hearth is prepared for another. The workman first detaches, by means of a long rod, any portions of metal that may be adhering to the sides of the furnace; he then presses down the fuel, throws in a fresh supply of coke, and levels it to the proper height: upon this he arranges six iron pigs, four parallel to the long sides of the furnace, and two across. The weight, which may vary from 20 to 30 cwt., takes about two hours in refining, and the

loss is from 13 to 17 per cent. In about a quarter of an hour the iron melts down, and falls in drops through the blast to the bottom of the furnace. A portion of the metal thus becomes oxidized, and, uniting with the silica of the fuel, and also with that formed by the oxidizing of the silicium of the metal, forms a fusible vitreous slag, which, being rich in oxide of iron, exerts a powerful decarbonising action on the iron on which it floats. To promote these changes, the blast is made to play upon the fused mass for a considerable time after the whole of the iron has been collected at the bottom of the crucible. During this time the fuel is lifted up by the motion caused in the metal by the escape of carbonic oxide produced by the reaction of the rich silicate of iron of the slag. When the decarbonization is thought to be sufficiently advanced, the hole *o* is opened, and the metal allowed to flow into the mould. A considerable quantity of cold water is thrown upon it, whereby it becomes extremely brittle and sonorous. The slags are then broken in pieces for the puddling-furnace. About 10 tons of cast-iron may be passed through the refinery in the course of twenty-four hours, with the consumption of from 4 to 5 cwt. of coke for each ton of metal refined. For the better kinds of iron, such as that used for the manufacture of tin-plates and iron wire, where the tenacity of the pure metal is required, coke is too impure a fuel; charcoal is therefore used; but as with this fuel the metal collects into clots or lumps, they are formed into a bloom which is conveyed to the helve, and flattened into thin plates, preparatory to being finished in another furnace.

In the puddling-furnace, shown in sectional elevation and plan, Figs. 1235, 1236, the hearth A is of fire-brick set on edge, or it is a plate of cast-iron, covered with a layer of slag, which is made to incline towards B, where there is a considerable fall to allow of the escape of the slags formed during the process of puddling; and they are removed by the *flosshole*, *h*. The hearth is about 6 feet long and 4 feet wide at the widest part, and taper





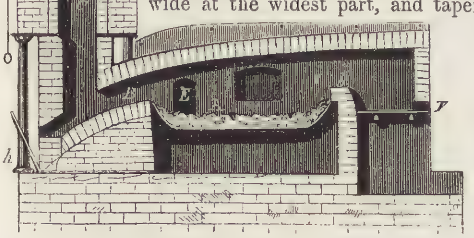


Fig. 1235. PUDDLING FURNACE.

to about 20 inches towards the chimney. It is heated by a fire at F, from which it is separated by a bridge *b* 10 inches high. The fire-bars are made movable for the purpose of removing the clinkers; and the draught is determined, through the furnace, by a chimney from 30 to 50 feet high, furnished at the top with a damper, D, which can be raised or lowered by means of a chain and lever. The opening at E, which communicates with the grate, is usually closed by heaping up the coal used for the fuel. The opening D communicates with the hearth, or sole of the furnace, and is chiefly used for working the metal with an iron bar during the process of puddling. It is closed by an iron frame filled with fire-bricks, and is raised by a chain and lever. Another opening nearer the chimney is used for charging and for cleaning out the furnace at the end of an operation. The whole furnace is very strongly built: it is encased with cast-iron, and held together by clamps and wedges. The chimney is also strengthened by iron ties.

The charge of fine metal is piled up on the sides of the hearth, until it nearly touches the dome, the centre of the sole being left clear for working the charge, and allowing the hot air to circulate about it. A portion of rich slag and iron scales is added; the doors and the damper at the top are closed, and fresh fuel is added to the fire. In about half an hour the metal begins to melt and flow on the bottom of the hearth. The man removes a small iron plate from a

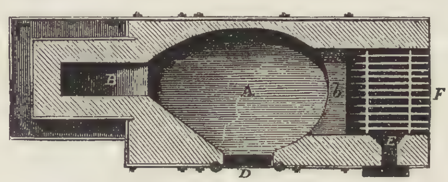


Fig. 1236. PLAN OF PUDDLING FURNACE.

hole in the working door, passes in an iron rod, and stirs up the molten metal so as to expose fresh surfaces to the oxidizing influence of the draft, and moves it further from the bridge, to prevent the whole of the charge from running together. When the charge is brought into a uniform pasty mass, the fire is lowered by gradually closing the damper, and, if necessary, throwing a little water into the furnace. The metal now, from the escape of carbonic oxide gas, assumes the appearance of boiling, and the gas burns at the surface with its characteristic blue flame. The metal is kept constantly stirred with an iron *paddle*, so as to expose fresh surfaces to the

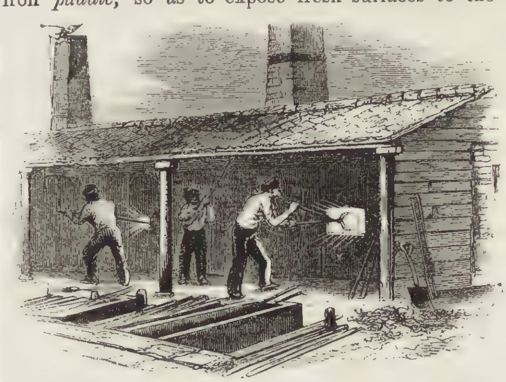


Fig. 1237. PUDDLING.

action of the gases; the direct action of the atmosphere is avoided as much as possible by keeping the working-door closed, otherwise the metal would be too much oxidized. By continuing to work the metal

it loses its consistency, and becomes *sandy*, or, as the workman calls it, *dry:* the evolution of carbonic oxide ceases, but the puddler continues to work the metal until it appears uniformly granular. The fire is then gradually urged, and the increased temperature causes the sandy particles to agglutinate; the iron is then said to *work heavily*. A portion of the slag is run off through the flosshole, and the man then proceeds to *ball up*, or to form the iron into balls. For this purpose he attaches a small portion to the end of his paddle, and, rolling it round, other fragments weld on to it. When a ball of 60 or 70 lbs. weight has been formed, it is detached from the paddle, and another is formed in a similar manner. When the whole of the charge has been balled, it is moved into the hottest part of the furnace, by means of a kind of rake called a *dolly*, and the fire is urged so as to weld the metallic particles. Each ball is then lifted out of the furnace by means of heavy tongs, and conveyed to the shingling hammer, or to the squeezer, where an iron rod is welded to it by way of a handle; the slag is pressed out, and the metal consolidated. The whole operation of puddling occupies about 2½ hours. At the end of the first 20 or 25 minutes, the metal begins to fuse, and in another hour is completely reduced to a sandy state, in which it is kept for another half hour, when the balling is commenced and occupies about the same time. From 10 to 11 charges, of 3½ to 5 cwt. each, are passed through the furnace in the course of 24 hours. The fine metal loses about 9 per cent. in the puddling, and occasions the consumption of about its own weight of coals.

The hammer used in compressing the balls is shown

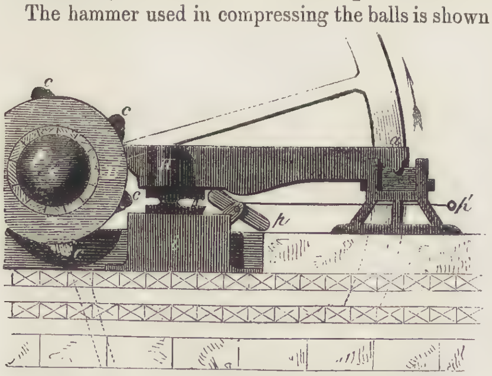


Fig. 1238. THE HELVE, OR SHINGLING HAMMER.

in Fig. 1238. It is made of cast iron, and is about 10 feet long, the weight of the helve being about 3½ or 4 tons. The axis *a* rests on heavy plummer blocks well secured by strong bolts passing through courses of wooden beams into a foundation of masonry. The wood serves to diminish the concussion of the ponderous mass. The head H is of wrought iron faced with steel, and weighs from 7 to 8 cwt: it is passed through a hole in the helve and well secured with wedges. The pane of the hammer *p* as well as that of the anvil is formed into a series of grooves for the purpose of better nipping and compressing the ball. The face of the anvil is supported on a block of iron *i* of about 4 tons weight. The head is raised by a number of cams *c*, fixed in a heavy collar B, called the *cam-ring bag*, about 3 feet in diameter, fixed to a powerful shaft S, which is turned by steam or water power assisted and regulated by a heavy fly-wheel, a portion of which is shown in the figure. In this way the head is lifted from 16 to 24 inches, and makes from 75 to 100 blows per minute. When it is desired to suspend the operation of the hammer, the rod *p'* is pulled, this brings into a vertical position the prop *p*, which supports the hammer and keeps it free of the cams.

The squeezer, which sometimes takes the place of the hammer, is shown in Fig. 1239. It consists of two

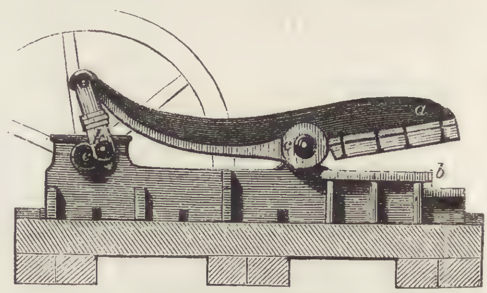


Fig. 1239. THE SQUEEZER.

powerful jaws *a b*, united at *c*, as in a pair of shears: the meeting faces of the jaws are furrowed with numerous grooves in order to hold fast the bloom. The lower jaw *b* is hollow to allow a current of water to flow through it to keep it cool. The upper jaw is set in motion by the shaft, and the crank *k* worked by the fly of which *c'* is the centre. This press is said to squeeze out the slag more thoroughly and expeditiously than the helve does, but on this subject there is a difference of opinion among iron masters. Nasmyth's steam-hammer has also been applied to the same purpose.

As soon as the slag is pressed out of the bloom, and while it is still at a red heat, it is passed between cylinders or *rolls*, Fig. 1240, which serve to compress and weld together the metallic particles, to express the last portions of the slag, and to draw out the iron into bars. Two sets of rolls are usually employed, the one called *roughing* rolls, which prepare the iron for the *finishing* rolls, the latter being differently grooved according to the section intended to be given to the bar The rolls R R' R'' R''', are mounted one above the other in pairs in a massive iron frame-work *u u*, connected by heavy couplings *d e*, tightly screwed together. Motion is communicated by strong toothed wheels made to turn either way, and the distance between the rolls is regulated by screws *s s*, attached to the bearings in which the trunnions work. The bearers *b* are connected at the upper part by stout iron bars, which are used to support the heavy tongs used in lifting the blooms. Below the roller frame is a channel through which a stream of water flows, and in it is collected the scale which falls from the surface of the heated iron while passing through the rolls; and a stream of water is made to play from a small pipe *t* upon each pair of rolls to keep them cool. The whole arrangement rests upon a massive foundation of timber, masonry and cast iron. The roughing

rolls are about 5 feet in the clear between the bearers, and 18 inches in diameter. "Each of these rollers has a series of from 5 to 7 regularly decreasing grooves of an elliptical form, so arranged that the shorter axis of the figure formed by the meeting of the corresponding grooves in the two cylinders is equal to the longer axis of the ellipse formed by the junction of the two grooves which come next in succession. The smaller axis of each ellipse is also invariably prependicular to the surface of the two cylinders, by the meetings of which it is formed; and for this reason, every bar which has passed between the rollers, is made to describe a quarter revolution before it enters the grooves which come next in the

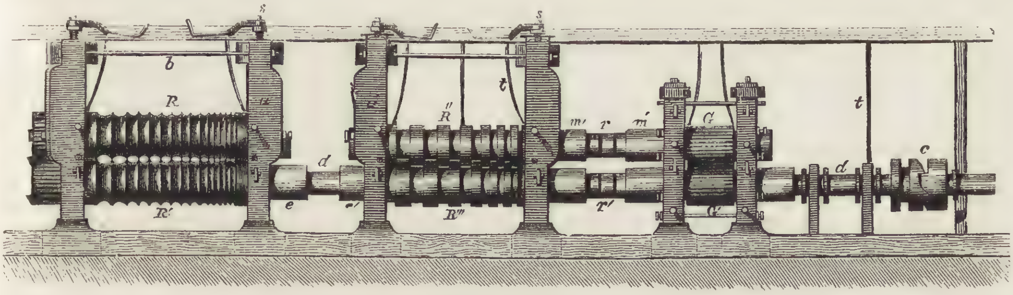


Fig. 1240. ROLLS.

series, and is thus equally compressed and drawn out in all its parts." The roughing and preparing grooves are usually arranged on distinct rollers, as in the figure, where R R′ represent the roughing rolls, and R″ R‴ those for forming the metal into bars, which are afterwards cut up by the shears, formed into faggots, welded together and drawn into bars of the required section. The first 3 or 4 grooves of the roughing rolls are roughened with teeth to cause the iron to pass through without slipping; and on a level with the bottom of the notches on the lower roll is a thick plate of cast iron, called an *apron,* for supporting the balls or masses of iron which are to be passed through the rollers.

The iron produced in this way is hard and brittle, and subject to flaws and imperfections. It is well adapted to railway bars, which are prepared by passing the bloom of puddled iron through grooved rollers of the section of the bar required. Good bar iron is, however, prepared by a separate process already indicated and now to be described. The bars from the roughing rolls are first cut up into short lengths by the shears, represented in Fig. 1241, consisting of two jaws, to which are firmly bolted cutting edges *a b* of hardened steel. The lower blade is fixed, but the upper one moves on a stout pin P, and is attached by a lever P R to a rod R M, which is connected by a crank to the shaft of the steam-engine, so that at every revolution of the axle by which the power is supplied, the jaws of the shears are made to open and shut alternately. Bars of an inch or more in thickness are easily divided by the jaws.

Fig. 1241. SHEARS.

A number of the short lengths thus produced are *piled* or faggoted together in a reverberatory furnace, which differs chiefly from the puddling furnace in having a larger grate in proportion to the hearth, a more intense heat being required. It is important to preserve the faggots from the oxidising influence of the air, so that no air is allowed to get to them, except that which has passed through the grate. When the faggots have attained the proper welding heat, they are taken out one at a time and thrown to the men at the finishing rolls, who pass them through the grooves as rapidly as possible, so as to get the required section and dimensions before the bar has cooled below the proper temperature for drawing. The finishing rolls are formed much more accurately, and revolve at a much higher speed than the roughing rolls. The latter make about 70 revolutions per minute: rolls of medium size about 140, and small rolls 230 or 240. The grooves gradually diminish in size, and the bar is passed from one to the other until the required size is attained. For small bar iron, 3 rollers placed one above the other are sometimes employed. Motion being directly communicated to the centre roll, this by means of cogged wheels causes the other two to revolve in contrary directions. The heated bar is passed between the first and second rolls, and then returned from the other side between the second and third. Sheet iron is made by passing the metal between smooth-faced rollers, which are gradually screwed nearer together as the desired thickness is being approached. Two sets are used; in the first the metal is roughed, and in the second finished off, and the surface made even and polished. The metal requires a reheating between the processes. The sheets intended for the manufacture of tin-plate are polished by being subjected to hydraulic pressure between two smooth surfaces of cast iron.[1]

The short lengths which compose the pile, tend to

(1) At the Breslau Exhibition of the Works of Industry, (1852,) some of the sheet-iron excited great attention; 7,040 square feet being rolled from a hundredweight of iron. This would give a thickness of about $\frac{1}{250}$th of an inch. It was proposed to use this *leaf*-iron as a substitute for paper. A bookbinder of Breslau exhibited an album made of it, and the iron pages turned as flexibly as paper. It is proposed to print for the tropics on these metallic leaves, and thus render books secure from the ravages of the white ant.

produce a fibre in the bar, which in good iron is always perceptible however perfect the weld. In rolling flat bars, the layers of the pile are kept horizontal, in order that the fibres may be as straight and parallel as possible. The experienced blacksmith in working up his bars always attends to the direction of the fibre, because by doing so he can make the most of his iron and increase the strength and toughness of the articles produced.

Bar iron is known in the market by the names *common iron, best iron, best best* or *chain-cable iron.* The different kinds of iron used in the manufacture of gun-barrels are described under GUN.

Two common defects of bar iron are known as *red short* and *cold short.* Red short iron is that which cracks when bent or punched at a red heat, although it may be sufficiently tenacious when cold. Cold short iron on the contrary is weak and brittle when cold, but can be worked without difficulty when hot. The quality of a bar of iron may be tested by nicking it at one side with a chisel and then breaking it or doubling it down at the notch. If the iron be cold short, it will break off at once with the blow of a sledge-hammer. But if the bar be of good quality, it will not break off but bend double, and those portions of it to the depth of the notch on both sides will separate a little from the body of the bar, and split up like a piece of fresh ash stick, exhibiting a clear, distinct, silky fibre. If this appearance be produced on a cold bar, and it be then raised to a cherry red heat and bent first in the direction of the pile, and then at right angles to it without cracking on the outer side of the bend, it is of excellent quality, neither red-short nor cold-short. A very small amount of phosphorus will make bar iron brittle, so small a proportion as 0·5 per cent. having been found to make it cold-short. Sulphur has been assigned as the cause of the red-short property of wrought iron; the presence of only 0·0001 of sulphur renders the iron very difficult to work at a welding heat. A cold-short iron is generally produced from a lean ore, in which case it has been found desirable to mix with it the rich red hepatic ore of Lancashire and Cumberland, which if smelted alone would produce red-short iron. In this way two opposite defects are made to correct each other, and iron of average strength is produced.

SECTION VII.—THE MANUFACTURE OF STEEL.

Iron in its pure form is known only to the scientific chemist; in its manufactured state it is never entirely free from carbon and other substances. The carbon appears to be only mechanically mixed with the metal, a peculiar process being required to effect a chemical union between the two, the result being a *carburet of iron* or *steel.* Less than ½ per cent. of carbon chemically combined with iron develops those remarkable properties which distinguish steel from iron, and adapt it to purposes for which iron is inadequate. Thus steel is so much harder than iron that it will cut and file it; steel will scratch the hardest glass; strike sparks with siliceous stones; it is denser than iron, has a finer grain, assumes a brighter and whiter lustre when polished, acquires greater elasticity retains magnetism more permanently, and does not rust so easily. When heated it assumes various beautiful tints of colour, and if suddenly cooled it becomes harder, more brittle, and less pliable than iron. Indeed the chief value of steel depends upon the ease with which it can be hardened and tempered to any degree between extreme hardness and softness.

Ordinary wrought iron may contain about 0·25 per cent. of carbon without having that property of steel whereby it becomes hard by being suddenly cooled in water: but with 0·50 to 0·60 per cent. of its weight of carbon, it emits sparks on being smartly struck with a flint. But the quantity of carbon required to render iron steely, depends greatly on the purity of the metal: shear steel after tilting contains from 1 to 1·5 per cent. of carbon: with more than 1·75 per cent. the steel cannot be welded. Iron with 2 per cent. of carbon cannot be forged; but with 1·9 per cent. of carbon iron may with care be worked under the hammer; and this appears to be the extreme point of carbonization beyond which steel is converted into cast iron.

A pure iron is required for the manufacture of steel, such as the charcoal iron of Sweden and Russia. A similar iron made at Ulverstone, and one from Madras, are also used. The foreign iron is imported in bars, on which certain marks are stamped by the manufacturers, and which distinguish it in the market. The most celebrated iron mine of Sweden is that of Dannemora, about 30 miles to the north of Upsala. The ore contains limestone, quartz, and actinolite, and affords from 25 to 75 per cent. of cast iron, which is as white as silver, crystalline, and very brittle. It is converted into malleable iron by heating in a bed of charcoal, and hammering out into bars, in which state it is whiter than common iron, less liable to rust, and distinctly fibrous in texture. This iron is known at Hull (the English port to which it is shipped) by the name of *Oregrund* iron, from the name of the port at which it is shipped. The marks which distinguish this iron are the *hoop L,* (so called from the letter L inclosed in a hoop); the G L, and the *double bullet.* Inferior Swedish iron is known by the marks *C and crown, D and crown;* the *Steinbuck,* and the *W and crowns.* All these marks are shown in Fig. 1242.

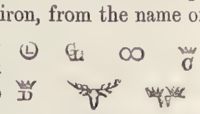


Fig. 1242.

It is remarkable that steel is produced on the continent of Europe by a process directly the reverse of that followed in England. We manufacture steel by the addition of carbon to pure malleable iron by what is called the process of *cementation.* In Germany, Styria and Silesia steel is made by depriving some of the better kinds of cast iron of the excess of carbon contained in them, one portion being got rid of by oxidation, while another portion is made to combine chemically with the fused mass.

The *cementing furnace* in which iron is converted into steel in this country is shown in section Fig. 1243. Externally it resembles a glass-house, and

consists of a cone or hood 30 or 40 feet high, serving to shelter the furnace within and also to carry off the smoke of the fuel. Within the furnace are two chests or troughs, C C, in which the bars of iron to be con-

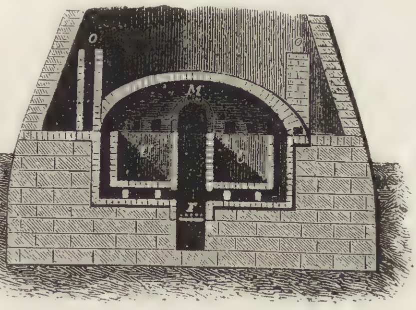


Fig. 1243. SECTION OF CEMENTING FURNACE.

verted are buried in pounded charcoal. These troughs are made of fire-tiles or firestone grit, and are capable of holding from 8 to 12 tons of bar iron. They are from 8 to 15 feet long, and from 26 to 36 inches in width and depth; but those of small capacity are said to produce the most uniform quality of steel. Below and between the troughs, and extending their whole length, is a grate, F, open at each end, where it is supplied with fuel, and the fire is kept up as equally as possible during the process, the flame being directed equally round the troughs by a number of air holes and flues, *o ò*, leading to the chimneys. The draught is further aided by an opening in the middle of the arch of the furnace. The troughs are, of course, filled before the fire is lighted, (the workman entering the furnace by the opening under M,) and the preparation of hard charcoal dust, called *cement*, varies with different steel converters: charcoal made from hard wood is preferred; but soot is sometimes used; as also a proportion of ashes (about $\frac{1}{10}$th) and a little common salt.[1] The workman sifts this mixture to the depth of two inches over the bottom of the troughs; puts in the bars upon their narrow edges, with a space between every two bars of from half to three quarters of an inch; powder to the depth of an inch is then sifted over this layer; a new series of bars is next made to fit into the interstices between the first, care being taken that no two bars are in contact, and in this way the troughs are filled to within 6 inches of the top. The filling is then continued with old cement powder, and this is lastly covered with refractory damp sand or fire-tiles, for the purpose of excluding the air, which, if admitted, would greatly injure or altogether stop the process of cementation. The entrances to the furnace being carefully closed, the fire is lighted below the troughs and carefully urged for two, three, or four days, until the proper cementing heat is attained: this heat is maintained during several days more until the iron has absorbed the quantity of carbon requisite to form the kind of steel required by the manufacturer. From six to eight days are sufficient for the production of moderately hard steel—such, for example, as that known by the name of *shear* steel; softer steel, for saws and springs, requires a shorter time; harder steel, for making the chisels used in cutting iron, takes a longer period; and for some purposes bars are exposed to two or three successive processes of cementation, and are hence said to be *twice* or *thrice converted*.

(1) The use of ashes and salt in the cement has not been explained. Mr. Phillips suggests that the salt may tend to vitrify any siliceous particles contained in the charcoal, and prevent their entering into combination with the iron under process of carburization.

In the centre of the end-stones of the cementing troughs are small holes, called *tasting holes*, corresponding with small iron doors in the outer brickwork; by these holes the workmen can occasionally draw out a bar to see how the transmutation is going on. This is judged of by the *blisters* which appear on the surface of the bars, which give the well-known name of *blistered steel* to this article. When by this process of *tasting* the change is judged to be complete, the fire is extinguished and the furnace left to cool for about a week, when the process for making blistered steel is finished.

This steel is very different from the bar iron from which it was produced. Its surface is covered with blisters, and on breaking a bar across, its texture is seen to be no longer fibrous, but granular or crystalline; the colour is white like frosted silver, and the crystals are large in proportion to the amount of carbon absorbed.

The cementation of steel may be effected by exposing the iron at a proper temperature to the action of carburetted hydrogen gas. Steel of excellent quality may be produced in this way, but the process does not appear to be sufficiently economical to admit of its being generally introduced. It has also been proposed to convert the retorts used in the manufacture of coal gas into cementing troughs: the bars of iron to be put in with the charge of coal, and taken out with the coke, or after a second charge of coal has been coked.

TILTING. The bar of blistered steel contains numerous fissures and cavities, which render it unfit for forging except into a few rough articles. To prepare it for forging into edge-tools and cutting instruments, it requires to be condensed and rendered uniform, which is the object of the next process, called *shearing*, the *shear steel* thus produced being originally employed in the manufacture of shears for cutting off the wool from sheep.[1] The process is also called *tilting*, from the circumstance of a tilt hammer being employed.

In some respects the operation of tilting resembles that of *shingling* described in the manufacture of iron; but the tilt hammer is differently arranged. In shingling, where only a slow motion is required, the hammer is lifted up by means of levers attached to a cam revolving under the nose of the helve. In the tilt hammer the cogs of a wheel are made to act on the tail of the helve, pressing it down, and thus

(1) Shear steel is also sometimes called *Newcastle steel*, from the circumstance of steel of this quality having formerly been made at Newcastle; a better quality introduced from Germany gave rise to the term, *German steel*.

causing an elevation of the head of the hammer, and a rapidity of motion, which could not evidently be produced by the arrangement of the shingling hammer; for, in this, the levers must be sufficiently wide apart, to allow the hammer head a clear space to fall through. In the tilt hammer, however, where the motion is applied at the tail, the number of levers may be considerably multiplied; because, from the position of the axle, the tail describes a very small arc between every two levers; and this small motion will cause the head to pass through a much larger space in the same time, thereby producing rapidity of motion, and considerable force. The construction of the tilt hammer will be better understood from Fig. 1244. The frame work is strongly secured to

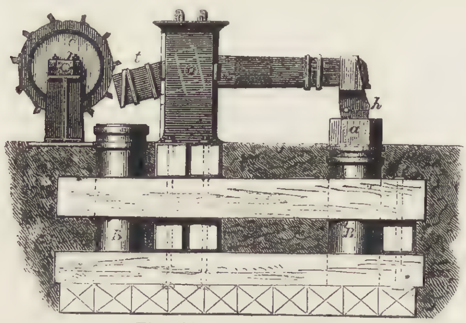


Fig. 1244. TILT HAMMER.

the masonry and timber of the foundations, so as to form a firm bed for the block. The shaft of the hammer is made of timber secured by wrought iron rings and fitted into a cast iron socket with trunnions or axles cast upon it, which turn in brasses in a block. The wheel C by which the hammer is elevated is furnished with ears or *tappits*, which, during the revolution of the wheel, engage the end *t* of the shaft and continue to depress it until disengaged, when the hammer head *h* falls with considerable force on the anvil, producing in this way from 150 to 360 strokes per minute.

The blistered steel is prepared for tilting by breaking the bars into lengths of about 18 inches, and binding four or more of these into a faggot by means of a slender steel rod. One of these fragments is left longer than the rest to serve as a handle, or a pole of iron is used for that purpose, as is shown in Fig. 1245.

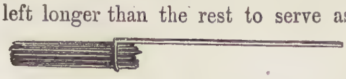


Fig. 1245.

The faggot is then raised to a welding heat in a wind furnace, and is covered with sand, which combining with a small portion of oxide of iron, forms a fusible slag over the metal, and prevents it from wasting or burning away. When first removed from the furnace it is placed under a forge hammer, which unites all the fragments and closes up internal fissures. The rod thus produced is again heated, the binding rings are knocked off, and the tilt hammer comes into operation. The workman is seated on a board, suspended by iron rods from the ceiling of the mill-house; whereby he is enabled with a very slight motion of his foot to advance or recede with ease and rapidity, so as to cause every part of the bar to receive the blows of the hammer in quick succession. As the anvil is nearly on a level with the floor, the workman is seated in a kind of pit excavated for the purpose; he is attended by two boys to bring hot rods and to remove them after they are hammered. "In small rods, the bright ignition originally given at the forge soon declines to darkness; but the rapid impulsions of the tilt revive the redness again in all the points near the hammer; so that the rod skilfully handled by the workman progressively ignites where it advances to the strokes. Personal inspection alone can communicate an adequate idea of the precision and celerity with which a rude steel rod is stretched and fashioned into an even, smooth, and sharp-edged prism, under the operation of the tilt hammer. The heat may be clearly referred to the prodigious friction among the particles of so cohesive a metal, when they are made to glide so rapidly over each other in every direction during the elongation and squaring of the rod."

A visit to the tilt house is by no means pleasant to a stranger; several hammer heads, each weighing from 150 to 200 pounds, falling from three to four hundred times per minute upon solid metal anvils, *a*, Fig. 1244, produce a stunning noise and a vibration which can be felt through the whole body. This vibration is checked as much as possible by carrying the foundation of the tilting apparatus to a depth of ten or twelve feet, forming a heavy mass of masonry; and the anvil is made to rest on a massive wooden pillar B, strongly secured by wrought iron rings, which is supported by, and forms part of the masonry.

By tilting, the steel is formed into bars of about an inch and a half broad, and three-eighths of an inch thick; all the loose parts and seams of the blistered steel are closed, and it is now capable of being polished, which could not be done before: it is also more malleable, and can be forged with the hammer into shears, edge-tools, and cutting instruments. The value of the steel increases with the amount of tilting which it receives: it is therefore not uncommon to cut a tilted bar into several pieces, form them into a faggot, and elongate this again into a bar or rod. The terms *double shear*, *single shear*, and *half shear*, express the amount of doubling and welding which the bars have received.

CAST STEEL. Steel is produced in the greatest perfection by the process of *casting;* that is, the bars of blistered steel being broken into fragments, are melted in crucibles and then poured, while in a fluid state, into ingot moulds. The neat required to produce this fusion is very great, so that the crucibles or melting pots require to be made with refractory fire-clay and with the greatest care, in order to exclude bubbles of air and extraneous substances, which might expand or ignite in the furnace, and thus endanger the stability of the melting pot.

The crucibles are made of Stourbridge clay mixed with one half of an inferior clay from Stannington, near Sheffield: a small quantity of coke dust and of fragments of old pots is added, and the whole is kneaded into a perfectly uniform and smooth mass. The clay is first mixed with water, worked up, and then spread

out in a thin layer on a shallow trough on the floor.[1] There it is kneaded during five or six hours by the naked feet of two men, who with a shuffling kind of

Fig. 1246. TREADING OUT THE CLAY, AND MOULDING THE CRUCIBLES.

motion go over every part of the surface, pressing it down quite flat; and so sensitive is the touch of their feet, (which are developed to an enormous size by this constant exertion,) that they can, by the difference in the tread, detect an air bubble, a fragment of straw or of dirt in the clay. The two latter they pick out with the fingers, and get rid of the air by making a slight incision with a knife. When the whole surface has been well trodden over, it is folded double and trodden out again so as to occupy the whole of the trough. If the reader has ever watched the domestic operation of making pastry, he will be able to form a good idea of the process of kneading clay for the steel-melting pots.

The crucibles are about two feet in height, and of the shape shown in section, Fig. 1249. They are formed in a cylindrical mould of cast iron *a a'*, Fig. 1247, which is open at the two extremities. This cylinder is inserted into a sole of cast iron *b b'*, firmly attached to a block of wood and having a raised circular edge. In the centre of the sole, corresponding with the axis of the cylinder, is a hole intended to receive the supporting rod of the inner mould *c*. This consists of a block of hard wood, the surface of which corresponds with the interior shape of the crucible: through the centre of this block passes a strong iron axis, the lower end of which rests in the hole already mentioned; the upper end, which is rounded, rises just above the circular cover of wood *e e'*. It will be seen that when the inner mould *c* is in its place, as in Fig. 1247, there is between its surface and the inner surface of the outer mould a vacant space of the form and dimensions required for the melting pot. The surface of *c* and the inner surface of *a* having been smeared with oil, a quantity of clay is put into *a*, and the central plug *c* forced down as far as it will go by hand: its further descent

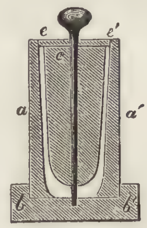


Fig. 1247.

Fig. 1248.

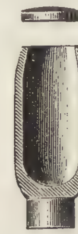


Fig. 1249.

is then urged by blows of a hammer upon the rounded head of the iron axis, until the lower end of the axis passes into the hole in the sole *b*. In order to disengage the moulded clay, the central plug *c* is pulled out and the hole in the centre stopped up: the outer mould with its contained clay is then lifted upon a block of wood mounted upon a stout iron rod, Fig. 1248, and of somewhat less diameter than the bottom of the pot, so as to press entirely upon the clay bottom when the mould *a a'*, lifted out of *b b'*, is placed upon the top of Fig. 1248. The mould is then allowed to descend slowly and with care, by which means the clay pot is left upon the top of the block of wood, while the mould *a a*, on reaching the ground, surrounds the rod, Fig. 1248. The upper part of the clay is then finished by hand: it is pressed slightly inwards and made to assume the form, Fig. 1249. The blocks on which the pots rest are short cylinders of clay: the covers, also of the same material, are thick discs slightly raised in the centre. Each crucible, which weighs about 25 lbs., is removed as soon as it is finished into a heated vault, where it gradually becomes dry; and some hours before being used the crucibles are brought to a red heat for the purpose of annealing them. A crucible can seldom be used for melting the steel more than three times without cracking; so that there is a constant demand for crucibles, as many as 108 being required per week for a ten-hole furnace.

On a level with the crucible-making department are the furnaces for melting the steel; these are ordinary wind furnaces placed in connexion with a tall chimney by which a strong natural draught can be obtained. (See Fig. 1250.) Each furnace is only just large enough to contain two crucibles and the proper amount of fuel; and it is lined with a plaster calculated to resist the intense heat. This plaster is formed of the dust of the roads in the vicinity of Sheffield, and is called *ganister*. The fuel employed is a dense well-made coke, broken into lumps of about the size

(1) Stourbridge clay contains—

Silica	46·1
Alumina	38·8
Combined water, and combustible and volatile matters	12·8
Carbon	01·5
	99·2

Hence, the only fixed principles of Stourbridge clay are silica and alumina. The Stannington clay contains small portions of manganese and lime, and a trace of oxide of iron. The melting pots fuse into a vitreous enamel of extreme hardness. They can only be used for three meltings, but if made of Stourbridge clay alone, they will stand six.

of a hen's egg. Immediately over each furnace is a trap-door, made of fire-bricks fastened in an iron frame opening into the casting house, which is a kind of shed entirely open on one side, while on the other ten trap-doors are seen, from the sides of which escape a few rays of red light indicative of the fiery furnaces below. In an adjoining shed the bars of blistered steel are broken into fragments, and the charge for each crucible, about 30 lbs., weighed out into tin trays, a small portion of black oxide of manganese being added to each charge, this substance being supposed to improve the quality of the steel. In some cases powdered charcoal forms part of the charge. Fig. 1250 shows the interior of the casting house and of the air-vault, with two crucibles, as

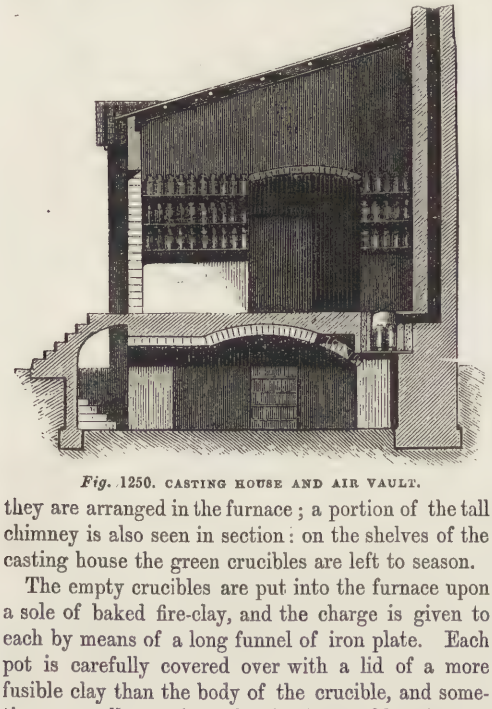


Fig. 1250. CASTING HOUSE AND AIR VAULT.

they are arranged in the furnace; a portion of the tall chimney is also seen in section: on the shelves of the casting house the green crucibles are left to season.

The empty crucibles are put into the furnace upon a sole of baked fire-clay, and the charge is given to each by means of a long funnel of iron plate. Each pot is carefully covered over with a lid of a more fusible clay than the body of the crucible, and sometimes a small quantity of bottle glass or blast furnace slag is put in above the steel fragments, so as to form a sort of vitreous coating to prevent the air from oxidizing the metal. When the pots are thus charged and covered in, the furnace is filled up with coke and kept well supplied. In about four hours the steel is in a state for casting, and as the time approaches the men occasionally lift up the various trap-doors and examine the crucibles, their eyes being accustomed through the fierce floods of heat which pour upwards from the furnace to detect the precise time when the metal is sufficiently fluid for casting.

While the steel is melting, the ingot moulds are prepared. These moulds, which are of cast iron, are of various sizes, according to circumstances; those which were used at the time of the writer's visit producing an ingot about two inches square, and two feet in length, a quantity equal to the contents of one crucible. When an ingot of unusually large size is required, such as for rolling into a piston-rod or a large plate for a circular saw, the mould is, of course, of proportional size, and receives the contents of two or more crucibles. Each mould consists of two parts, forming a long hollow cavity, the parts fitting accurately together: they are held together by a clamp of iron, Fig. 1251: and are kept upright by resting against the angles of a

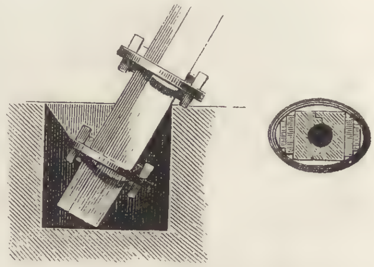


Fig 1251.

pit in the floor of the casting house. Previous to putting the moulds together, the interior is smoked by being laid across a pitch fire, the internal coating of carbon thus imparted preventing the liquid steel from adhering to or melting the mould.

Just before drawing the crucibles, each man puts on sacking leggings, and an apron of the same material; he next visits a tank, and thoroughly soaks these in water, as a further protection against the fierce heat to which he is about to be exposed; then, throwing open the trap-door of one of the furnaces, he removes a portion of the white hot coke, and, planting his feet one on each side of the yawning fiery furnace, thrusts down a pair of tongs, Fig. 1252, furnished with concave jaws for grasping the crucible just below the swell, and then, with a motion between a jerk and a swing, raises the glowing burden. A second man immediately removes the cover; a third man, and the most skilful, grasps the crucible with tongs held horizontally, raises it, and slowly inclines it to the mouth of the ingot mould, his attendant with a pair of tongs removing any portions of cinder or slag from the surface of the molten metal. Considerable skill is required in *teaming*, as the operation of transferring the metal from the crucible to the ingot mould is called. It must be poured directly down the centre of the mould, without touching the sides; for were it to do so, it would instantly remove the carbonaceous covering, and burn a piece out of

Fig. 1252.

the mould. The metal flows as liquid as water, and with the gurgling sound of water if poured under similar circumstances; but the extremely high temperature of the molten steel is shown by the white heat slightly tinged with blue. As the stream falls, minute portions of it combine rapidly with the oxygen of the air, and take fire, producing brilliant scintillations. The fire even communicates itself to the ingot towards the end of the process of teaming, and the mould then appears like a brilliant firework; but this combustion is soon stopped by the insertion of a solid plug. As the ingot immediately solidifies, each mould is opened directly after the teaming, and the

ingot is turned out in a red-hot state. This rapid cooling of the steel and the thin film of soot effectually protect the mould from the destructive action of the liquid metal which would otherwise ensue.

Fig. 1253. CASTING STEEL INGOTS.

The men engaged in these operations have that peculiar look about the eyes which shows the nature of their occupation; but otherwise, we believe, the business of steel refining is not considered unhealthy, and the men receive good wages.

As soon as the crucible is emptied of its contents, it is returned to the furnace, to receive a fresh charge; and as four hours are required for the melting, there are three casts in the twelve hours during which the men work. The charge is introduced by means of a funnel of plate iron, Fig. 1254, into which a rod is inserted, to break up the charge, and prevent a heavy mass from falling at once into the crucible, which might cause its fracture.

Fig. 1254.

Cast steel is much denser and harder than tilted steel, but it requires care in forging, because a little above a cherry red heat it is very brittle. Two surfaces of cast steel may be welded together by interposing a thin film of borax; and cast steel may be firmly united to a polished surface of iron by placing the iron in the mould into which the steel is poured. The two metals can then be rolled and worked out together into rods adapted for forging.[1] Fig. 1255 shows the operation of rolling steel. It does not differ greatly from rolling iron, and therefore need not be further described.

When steel is moistened with a drop of dilute

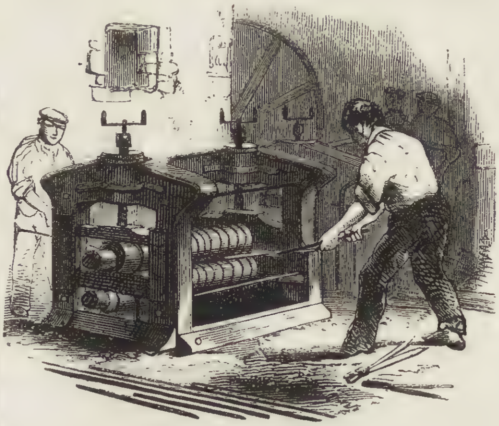


Fig. 1255. ROLLING STEEL.

nitric acid, a dark grey spot is produced: malleable iron so treated yields a spot of a green colour.

When steel is fused with very small quantities of platinum, of silver, rhodium or iridium, its hardness is greatly increased; but these alloys have not yet been used in manufactures.

Sheffield and its neighbourhood is the great seat of the steel manufacture. The annual quantity of steel produced during the last 5 years, varies from 16,000 to 17,000 tons from foreign iron, and from 1,500 to 2,000 tons from iron of British manufacture. The number of converting furnaces is upwards of 120, each of which is capable of converting weekly 6 tons of iron: the coal consumed in the process is about equal to the weight of steel produced. There are also above 100 melting furnaces for cast steel, each containing about 10 holes for crucibles: 4 tons of coke are used in making 1 ton of cast steel, and each furnace of 10 holes produces 4½ tons of cast steel per week.

IRRIGATION. This art, as practised in warm countries, has been noticed in our article DRAINAGE, to which with its illustrations we refer the reader, but the mode of irrigating an English water-meadow is essentially different. In the East it is the ordinary custom to introduce water on the soil, and leave it in a stagnant condition for months, the water thus affording a valuable and necessary protection both to the soil and the tender plants, from the effects of the great heat. But in our own country, where no such necessity exists, great care is taken that the water shall not accumulate on the soil so as to become stagnant, while at the same time it shall be supplied in ample quantity all the time the plants are growing. Hence in our best systems of irrigation, the draining is as essential as the flooding, and while one set of channels is made to distribute the water slowly and regularly over the meadow, another set is devoted to the opposite purpose of carrying it off. Thus a constant flow of the water is maintained, accelerated or retarded by small hatches, so as to keep it at the desired level. The feeders, or channels which supply the

(1) Various particulars respecting the forging, hardening, and tempering of steel, are given under CUTLERY. See also ANNEALING—CASE HARDENING, &c. The damasking of steel is noticed under GUN. In this notice of the manufacture of steel, we have availed ourselves of information contained in the Editor's work on the "Useful Arts and Manufactures of Great Britain." The pictorial illustrations are from drawings made for the purpose by Mr. Prior, at Sheffield. The reader interested in the manufacture of steel, will do well to study the elaborate memoirs on this subject, by M. F. Le Play, in the Fourth Series of the *Annales des Mines*. The memoir contained in vol. iii. 1843, is devoted to the fabrication of steel in Yorkshire, while that in vol. ix. 1846, is on the fabrication of steel in the north of Europe.

water, are formed on the top of low ridges, the drains in the hollows between them, and this further aids in keeping up the flow of the water.

In preparing to irrigate lands, the first step is to take the level, and to ascertain what are the supplies of water to be obtained above that level, and whether such supplies are available without deteriorating the property of others, or withdrawing water from some important use elsewhere. If no natural supply of water can be obtained above the level, and if water cannot be conducted to a reservoir for the purpose, then the irrigation of the land is impossible. On the other hand, it does not follow as a matter of course that every low land where a supply of water can be readily obtained is capable of irrigation, for there must also be the means of carrying off the water, as well as of bringing it on.

The most general and natural position for water-meadows is on the banks of running streams. At some point in the course of the river a canal is dug along the bank, and carried perhaps to a considerable distance from the river. Into this a portion of the water is diverted which will keep the same level as that part of the river where it has its origin: in some cases a dam D, (Fig. 1256), is constructed across the river R, so as to secure a large quantity of water at the most advantageous time for irrigation. A certain command of water being thus obtained, it is directed into a main channel or conductor *a*, in connexion with various smaller channels or feeders. From these the water overflows into the drains with which they are intersected, and which carry it into the main drain *b*, whence it is conveyed back again to the river, unless there be other lands at a lower level to which it can be transferred, when the main drain in its turn becomes a conductor to a second system of feeders, and so on. But this method, which is called *catchwork*, is only available when there is a considerable fall of water, and a gentle declivity towards the river. It is also only desirable when the supply of water is limited, for its fertilizing qualities rapidly deteriorate.

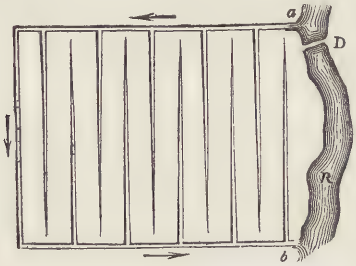


Fig. 1256.

The best season for irrigation is not always that in which the heat and drought are the greatest. In fact, at such season, much mischief would be done by injudicious flooding, while in the depth of winter, when it might be supposed that watering is needless, valuable results are often obtained from the practice. "During frost," says an experienced writer, "when all dry meadows are in a state of torpor, and the vegetation is suspended, the water-meadows, having a current of water continually flowing over them, are protected from the effect of frost, and the grass will continue to grow as long as the water flows over it. Too much moisture, however, would be injurious, and the meadows are therefore laid dry by shutting the flood-gates, whenever the temperature of the air is above freezing. By this management the grass grows rapidly at the first sign of spring. Before the dry upland meadows have recovered the effects of frost and begun to vegetate, the herbage of the water-meadows is already luxuriant. As soon as they are fed off, or cut for the first crop of hay, the water is immediately put on again, but for a shorter time; for the warmer the air, the less time will the grass bear to be covered with water. A renewed growth soon appears, and the grass is ready to be cut a second time when the dry meadows only give their first crop. Thus by judicious management, three or four crops of grass are obtained in each season, or only one abundant crop is made into hay, and the sheep and cattle feed off the others." The soil best adapted for a water-meadow is a gravel or other porous soil free from stagnant water, hence under-draining is sometimes necessary, before the laying out of a good meadow. When the beds are properly laid out and rolled, grass seed is sown, or the turf parings laid down again, or tufts of grass from old sward are spread over and soon cover the ground.

The herbage produced in England is some of the best in the world: it is more varied, close, and fine than that of southern countries, and more rich and vigorous than that of northerly climates. It is watered by numerous rivers, which flow through districts of great fertility, and afford valuable nutriment, owing to the quantity of animal and vegetable substances with which they are enriched. Liquid manure is also applied to the land in the same way, being distributed and carried off like water. Muddy water is sometimes let into a field, and allowed to remain until it has deposited its sediment, when it is let through sluices. This is called *warping*, and is practised where circumstances will allow of it, at the mouths of rivers, where the tides and the fresh water meet. At the estuary of the Humber the water is carried several miles inland, and will deposit in the course of a single season more than a foot of rich soil. When lands become gradually inundated through natural causes, if the flooding does not continue too long, it may have a beneficial effect by the deposits left behind; but when the inundation begins to subside, it must be made to run off entirely, and not be left to settle in pools, which would destroy the grass.

ISINGLASS. See GELATINE.

ISOCHRONISM—ISOCHRONOUS, (from ἴσος, *equal*, and χρόνος, *time.*) Vibrations or oscillations performed in equal time are said to be isochronous. It is a remarkable property of all systems which are in stable equilibrium, that when disturbed therefrom by a greater or less impulse, the oscillations by which they recover their original position are all performed in the same time, or so nearly so, that any acceleration or retardation is quite imperceptible. This valuable property of isochronism is taken advantage of in the construction of instruments for measuring time. See HOROLOGY.

ISOMERISM, (from *ἴσος, equal,* and *μέρος, part,*) a term applied to that natural law by which certain bodies may contain the same elements in the same ratio, and yet possess distinct physical and chemical properties. Isomeric bodies are of constant occurrence in organic chemistry. For example, formic ether and acetate of methyle are isomeric, both containing $C_6H_6O_4$; but as a difference in chemical properties is fairly and properly attributed to a difference in *constitution,* if not always in composition, it has been attempted to show that isomeric bodies vary in this way. Thus formic ether may consist of formic acid C_2HO_3 combined with ether C_4H_5O; and acetate of methyle may consist of acetic acid $C_4H_3O_3$, and the ether of wood spirit C_2H_3O.

ISOMORPHISM, (from *ἴσος, equal,* and *μορφή, shape* or *form.*) Certain substances of similar chemical constitution possess the remarkable property of exactly replacing each other in crystallized compounds without alteration of the characteristic geometrical figure. Such bodies are said to be *isomorphous.* For example, magnesia, oxide of zinc, oxide of copper, protoxide of iron, and oxide of nickel are isomorphically allied. The salts formed by these substances with the same acid and similar proportions of water of crystallization, are identical in form, and when of the same colour cannot be distinguished by the eye: the sulphates of magnesia and zinc may be thus confounded. The sulphates, too, all combine with sulphate of potash and sulphate of ammonia, giving rise to double salts, whose figure is the same, but quite different from that of the simple sulphates. In the same manner alumina and peroxide of iron replace each other without change of crystalline figure. The alumina in common alum may be replaced by peroxide of iron, the potash by ammonia or by soda, and the figure of the crystal remain unchanged.

Mixtures of isomorphous salts cannot be separated by crystallization, unless of very different degrees of solubility. A mixed solution of protosulphate of iron and sulphate of copper, isomorphous salts, yield on evaporation crystals containing iron and copper. But if, before evaporation, the protoxide of iron be peroxidized, the crystals will be free from iron. The peroxide salt of iron is not isomorphous with the copper salt, and easily separates from it.

When compounds thus correspond, it is inferred that the elements which compose them are also isomorphous. It is difficult, and often of course impossible, to ascertain the crystalline figure of most of the elementary bodies, and the difficulty is increased by the fact that many of them are *dimorphous,* that is, they exhibit two forms.[1]

IVORY. A beautiful and compact substance, obtained from the tusks of the elephant, the narwhal, the walrus, and the hippopotamus, and also from the teeth of the same animals. The best and largest supply is however from the elephant.

The male elephant when full grown has two tusks, varying considerably in size in different animals, but most valued when they are large, straight, and light in colour. These tusks are hollow at their insertion into the jaw, and for a considerable space therefrom, but become solid as they taper towards the extremity. The principal sources whence they are obtained are the western coast of Africa and Hindostan; but the African tusks are most esteemed, as being denser in texture, and less liable to turn yellow. By an analysis, the African show a proportion of animal to earthy matter, of 101 parts to 100; while in the Indian it is 76 to 100.

The applications of ivory are so numerous that a large demand for elephants' tusks has existed for a lengthened period. During twelve years at the close of the last century, the imports into Great Britain amounted on an average to 1,576 cwts. annually; in 1831 and 1832 they had increased to 4,130 cwts., of which 2,950 cwts. were retained for home consumption. Now, reckoning the medium weight of a tusk at about sixty pounds, it is evident that the imports of the years last named would require 7,709 tusks, or the destruction of 3,854 male elephants. But since that period the imports have so greatly risen, that in Sheffield alone 180 tons of ivory are worked up annually into knife-handles, &c. It is also affirmed that of the quantity of tusks imported, although some weigh from 60 to 100 pounds, yet the number of small tusks is so enormous, that an average weight of nine pounds can only now be reckoned on; in which case 45,000 tusks, from 22,000 elephants are required to supply the demand of this great cutlery mart of England. Occasionally, it is allowed, broken or shed tusks are collected, or those of animals which die a natural death are obtained; but the supply from these sources is never very large, so that the slaughter of elephants, after all deductions made, is going on at a rate which leaves it a constant wonder that the breed of this noble animal has not been sensibly diminished. The value of the ivory consumed in Sheffield is very great; but there are also other seats of manufacture, and ivory is wrought into the forms of chess-men, billiard-balls, the keys of musical instruments, thin plates for miniatures, mathematical and other instruments, and an immense variety of small objects of use, amusement, or ornament. None of our manufacturers have yet reached the consummate skill of the Chinese in the workmanship of ivory, chiefly remarkable in their concentric balls, their chess pieces and models. Yet the adaptation to useful purposes of this valuable substance is fully understood by those who cannot rival the exquisite minuteness of Chinese art. A manufacturer of surgical instruments in Paris is in the habit of rendering ivory flexible for use as tubes, probes, &c., by acting on the well-known fact, that when bones are subjected to the action of hydrochloric acid, the phosphate of lime, which forms one of their component parts, is extracted, and thus bones retain their original form, and acquire great flexibility. M. Charrière, after giving the pieces of ivory their required form and polish, steeps them in acid, either pure or diluted, until they become supple and elastic, and of a slightly yellow colour. In the course of

(1) Fownes' Manual of Elementary Chemistry. 1850.

drying the ivory returns to its original hardness, but its flexibility can be easily restored by surrounding it with wet linen, or by placing wet sponge in the cavities of the pieces. In some cases, the articles have been kept in the acidulated water, in a flexible state, for a week, without change or injury, and without acquiring any taste or disagreeable smell.

It has lately been ascertained that the decay of articles in ivory can be effectually checked, even when its progress has advanced so far as to cause the specimens to crumble away under the hands. Some of the works in ivory forwarded by Mr. Layard from Nineveh, were found on their arrival in England to be in a state of rapid decomposition. Professor Owen was consulted on the subject, and he suggested a remedy which has proved entirely successful, thereby preserving to this country these curious relics of ancient art. Concluding that the decay was owing to the loss of gelatine in the ivory, he recommended that the articles should be boiled in a solution of gelatine. Under this process they became apparently as firm and solid as when they were originally entombed.

The tusks of the hippopotamus afford a very hard and white ivory. These are usually short and much curved, hollow at the place of insertion, and covered with a glossy enamel. They vary in weight from three or four pounds to thirty. These are highly prized by the dentists, and are better adapted than any other ivory for making artificial teeth. The thick coat of enamel which covers them has first to be removed, for this entirely resists steel tools, and under it is found a pure white ivory, with a slight bluish cast. The parts rejected by the dentists are used for small carved and turned works. The horn or tooth of the narwhal is also hard and susceptible of a fine polish. The largest size is ten feet long; at the lower extremity it forms a slender cone of a twisted or spiral figure.

Another and a very remarkable source of ivory is that which supplies almost the whole of the ivory-turner's work made in Russia. Along the banks of the larger rivers of the Russian Empire, and more particularly those of further Siberia, thousands of tusks are annually dug up, which once constituted the weapons of defence of a species of elephant or mammoth now extinct. These form what is called *fossil ivory*, but they have not undergone the changes usually understood in connexion with the term fossil, for their substance is as well adapted for use as the ivory procured from living species. So numerous are these tusks, that they are occasionally exported from Russia, being cheaper than recent ivory. They are rarely to be met with in England, except in museums. Mention is made, however, of one which measured 10 feet in length, and was solid to within 6 inches of the root, weighing no less than 186 lbs.: this was cut up into keys for piano-fortes.

There is a substitute for ivory now in general use, which it is necessary to notice here. It is the fruit of a species of palm, imported from Peru for some time past into the European market, and named by two Spanish botanists, who met with it in the groves of Peru, *Phytelephas macrocarpa*. These writers also supply the following description:—"The Indians employ the leaves of this most beautiful palm as a covering to their cottages. The fruit at first contains a clear insipid fluid, with which travellers quench their thirst; this fluid afterwards becomes gradually sweet and milky, and at length acquires solidity, so as to be as hard as ivory. If the fruit be gathered while the juice is fluid, the latter soon becomes acid; but when allowed to attain perfection, the kernels are of sufficient hardness to be employed by the Indians as knobs for walking-sticks, reels of spindles, and little toys, which are white, and perfectly hard while dry; if they are put under water they soften, but on drying, their hardness is restored. Bears eagerly devour the young fruit." Two species of this palm are recognised, the *P. macrocarpa*, or large-fruited, and *P. microcarpa*, or small-fruited. The vegetable ivory is in fact the albumen or nutritious substance surrounding the embryo, and which in some other palms, as the cocoa-nut palm, constitutes a beautiful and firm substance lining the shell. The vegetable ivory is enclosed in a hard rind, some of which generally adheres to it as imported. The Doum Palm has a similar albumen, which is turned into beads for rosaries.

The African ivory, as already stated, is superior to any other: its appearance, when first cut, is mellow, warm, and transparent, almost as if soaked in oil, and with very little appearance of grain or fibre; the oil dries considerably by exposure, and a permanent tint then remains, a few shades darker than writing paper. The Asiatic ivory is more dead-white at first, but is more disposed of the two to turn yellow afterwards. It is also less dense, and does not take so high a polish. The choice of ivory is accompanied with much uncertainty, even to experienced buyers. The tusks are received in all varieties of size and figure. They may be 8 or 10 feet long, or only as many inches. They may weigh (as we learn from the magnificent specimens in the Great Exhibition), 325 lbs. the pair, or they may not reach as many ounces. Mr. Holtzapffel mentions a small and hollow tusk in his possession, which only weighs $2\frac{1}{2}$ ounces. Their curvature may describe a simple half circle, or they may be curved in two directions, the tusk inclining to the shape of the letter S. The outside may be dark-coloured almost to blackness, or it may run through all the varieties of light and deep orange, hazel, and brown; their ends may taper off to a fine point, or they may be very much worn away, or they may end abruptly as if broken off.

The buyer, therefore, has to make the best selection he can by choosing a tusk as nearly straight, solid, and round as possible, with a smooth rind free from cracks, and a point that gives evidence in the worn part, that the tusk is of the desired fineness of grain. Yet after all precautions, it is only after the first cut of the saw that the quality can be really determined. Sometimes the interior exhibits a succession of layers or rings, of different shades and degrees of transparency; sometimes the solid parts of the most beauti

ful and transparent tusks have long oval patches of opaque white ivory, in some cases a regular grain is observable, almost like the engine-turning of a watch-case; in others no grain is perceptible; occasionally there is a deficiency of animal oil, and the ivory crumbles under the workman's tool; or there may be the serious defects of darkness of colour, and coarseness of grain. In rare instances a considerable portion of the tusk is found to have been injured by a musket ball, the iron or leaden bullet being enclosed in it. Two instances, if not more, have occurred in which these bullets were of gold, showing that the shot was fired by royal hands, for it is the reputed custom among Eastern potentates to use gold or silver bullets in their sports. One of these golden bullets is stated to have been cut through by a comb-maker in dividing a tusk. The portion of the tusk thus injured, is generally useless for any ornamental purpose for many inches each way around the ball; but cases have occurred in which a ball, and even a spear-head, has entered at the thin part near the skull of the animal, and become embedded without injury to the external surfaee.

Great economy is used in cutting up the tusks, so that the only waste may be that which arises from the passage of a thin saw between the several pieces into which it is divided; and even here it can hardly be termed waste, for the clean saw-dust of the ivory is sometimes used in making jelly. Every portion is, in fact, turned to some account, the outside rind being used for handles of pen-knives, &c., and the scraps burned in retorts for the manufacture of ivory black, used in copper-plate printers' ink, and for other purposes. The saw used in cutting up the ivory is about the fortieth of an inch thick, with rather coarse teeth, about five or six to the inch: it is stretched in a steel frame to keep it very tense. The sawing is commenced at the root end, and two or three pieces are cut to the lengths of such articles as can be made in that thinner portion of the tusk. The blocks are rarely cut more than five or six inches long. As the solid part of the tusk is reached, the blocks have to be greatly subdivided; perhaps longitudinal slices have to be cut for miniatures, or the taper handles of knives and razors have to be economically severed by cutting the slabs wedge form, the thick end of one against the thin end of the next, and then subdividing by parallel or inclined cuts, made either with the saw just described, or with the circular saw. The entire division of each block or length of tusk is settled and accurately marked in pencil upon the end of the piece, before the saw is used. When the tusk is to be used for turnery work only, the first cut is usually made where the hollow ends, which is ascertained by thrusting a wire up the tusk. Unless the latter is extremely curved, the principal part is formed into cylinders or rings, but the greater the curve the shorter the pieces that can be prepared from it without waste. The mode of centering the pieces, or placing them in the lathe, is thus described by Mr. Holtzapffel:—" The first process in preparing to rough-turn the block, is to fix it slenderly in the lathe between the prong-chuck and the point of the popit-head, and its position is progressively altered by trifling blows upon either end, until when it revolves slowly, and the common rest or support for the tool is applied against the most prominent parts, *a*, *e*, and *c* respectively, the vacancies or spaces opposite to each at *d*, *b*, and *f* shall be tolerably equal, so that, in fact, about a similar quantity may have to be turned away from the parts *a*, *e*, and *c*, for the production of the cylinder represented by the dotted lines within the figure.

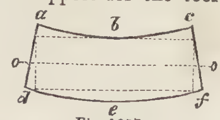


Fig. 1257.

The centres having been thus found, they should be made a little deeper with a small drill, and then the one end of the block being fixed upon the prong-chuck, the opposite extremity, supported by the centre, is turned for a short distance slightly conical, ready for fixing in a plain boxwood-chuck, or a brass chuck lined with wood to complete the rough preparation, unless, indeed, it is entirely performed upon the prong-chuck. With the decrease in length less attention is requisite in the centering, on account of the interference of the curvature of the tooth, and the pieces may at once be rasped to the circular form, and then chucked, either in a hollow chuck, or else by cement or glue, against a plain flat surface." It is recommended, however, that the amateur become familiar with the various methods of chucking on less costly materials before he largely employs ivory. Pieces of ivory in which there is a small hollow in the centre, are temporarily rendered solid by rasping a piece of beech wood, and driving it in; the work can then be centred as just explained with the hollow pieces; the process of turning is repeated on the inside, a side cutting tool, with a long handle for a secure grasp, being used, and the tool held very firmly, for which purpose the sliding rest is very desirable. When thin rings or short tubes of ivory are required, they are frequently cut one out of the other in the lathe with the parting tool, as in Fig. 1258.

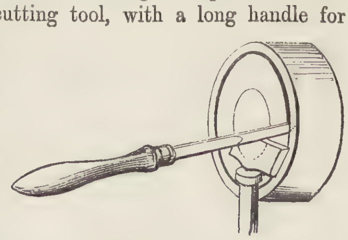


Fig. 1258.

Works intended strictly to match each other require to be cut from the same tusk, where this is possible, it being almost impossible to match works from different tusks in colour, transparency, and fibre. Works in ivory, too suddenly exposed to heat and dryness, are apt to split: on this account they should never be placed on hot chimney-pieces, or under the direct rays of the sun. Ivory resembles wood in the changes it is liable to from warping and splitting. There are some woods, indeed, less liable to vary than ivory, such as box-wood and lance-wood. In the recent Parliament Survey, drawing scales made of these woods were sanctioned by the Tithe Commis-

sioners, as being next in accuracy to metal, while ivory scales were quite rejected, owing to their variation in length under hygrometrical influence. The change in the length of ivory articles does not, however, equal that of their width; thus billiard balls are apt to become different in their two diameters: the best are made out of tusks scarcely larger than themselves. There are various recipes for bleaching ivory when it has become discoloured, but they appear to be of very little value.

IVORY-BLACK. See CARBON, vol. i. p. 315.

JACQUARD APPARATUS. See WEAVING.

JADE. This name has been given to serpentine, nephrite, and saussurite, but is usually applied to nephrite, a massive, tough, translucent mineral, composed chiefly of silica and magnesia, with or without alumina, oxide of iron, and lime, but varying in constitution. In New Zealand and China it is valued for its supposed medical properties, and is carved into images, and polished down into amulets and various fanciful shapes. Some of the mineral from China called Yu, or Jade, is however, supposed to be prehnite. Jade is polished by lapidaries like carnelian, but only takes a greasy, and not a brilliant polish.

JALAP. A common and useful medicine, obtained from the roots of a species of Convolvulus (*C. Jalapa*) chiefly obtained from Vera Cruz, and named after the town of Xalapa or Jalapa in the interior. The roots are collected in March or April, before their resinous juices are weakened by the development of the young shoots: some of them are of great size, weighing as much as 50lbs. They are divided into portions, and hung in nets over a fire to dry. In commerce, jalap is often adulterated with roots of white briony, which are white or grey, spongy and not resinous, whereas genuine jalap is hard, resinous, with a brown shining fracture. 100 parts of the dry root have been found to yield ten parts resin, forty-four parts gummy extract, twenty parts woody fibre, and twenty nine parts starch, albumen, salts of lime, potash, &c.

JAPANNING. A method of varnishing articles in wood, metal, and other substances, originally practised by the natives of Japan, with a peculiar lacker obtained by making incisions in the lower part of the trunk of a tree, the growth of their islands, and collecting the juice. This juice is at first like cream, but becomes black by exposure to the air: it hardens better than any other lacker, and is sometimes brought over to this country, but is not generally used. The Japanese method of employing this lacker is said to be as follows:—After exposing it to the air for many hours, until it becomes of a deep black, and adding a fine powder consisting of charred wood, they then spread the lacker thinly and evenly over the article, and dry it in the sun. Another coat is then laid on, and dried as before. It is soon extremely hard, and will bear polishing with a smooth stone and water, until it becomes as even as a plate of glass: it is then wiped dry, and the forms of figures and other ornaments are traced with a pencil dipped in varnish made of boiled oil and turpentine. Before this varnish-tracing is quite dry, gold or silver leaf is laid on, and the whole then receives a finishing coat of the varnish.

Our method of japanning differs from this in certain particulars. For black japanned works, the ground is first prepared with a coating of black, consisting of drop ivory-black mixed with dark-coloured animè varnish. This coating is well dried in a stove, and then varnished three or four times, the work being well dried between each. If coloured grounds are required, one or two thick coats of colour mixed with varnish are first laid on, and several varnishings and dryings complete the work. The ordinary painter's colours, ground with linseed oil or turpentine, and mixed with animè varnish, enable the workers in japan goods to produce a variety of effects according to their taste and fancy. The articles may be black or brown with gilded edges, or they may imitate marble, fine-grained wood or tortoiseshell, the last named being produced by vermilion with a varnish of linseed oil and umber. The colours most in request for this kind of work are flake-white or white-lead, Prussian-blue, vermilion, Indian-red, king's-yellow, verdigris, and lamp-black, with numerous intermediate tints produced by their mixtures. The varnishes employed are copal, or a varnish composed of seed-lac, or of gums animè and mastic. The lac varnish is the best as it respects hardness, but is too high coloured to be used alone on the more delicate grounds: it is therefore mixed, for such purposes, with gum-varnish, or it is superseded by copal varnish. Copal or animè varnish made without driers is applied two or three times, or as many as five or six times to the best works, to protect and give brilliancy to the colours.

It frequently happens that the articles to be japanned are either too coarse and soft to receive the lacker, or their substance is not sufficiently smooth without priming and preparation. Perhaps every workman has his own favourite method of preparation, and of mixing his varnishes; but it must be remarked, that whatever the care employed, works executed on an artificially prepared ground can never be depended on for durability, being much more liable to crack than those which are lackered on the solid substance of the object itself. The priming is of size and chalk or whiting, mixed up to a proper consistence to be laid on with a brush. It should be left a day or two to dry, and then brought to a proper smoothness of surface by rubbing with rushes, and then by the application of a wet cloth. When thoroughly dry the grounds are laid on smoothly with a brush, and finished by varnishing and polishing with rotten stone, or if the ground be white with putty or starch and oil. A brilliant ground is sometimes formed by laying it entirely in gold. This is done by going over the work with japanner's gold size, and when this is nearly dry but still clammy, it is covered with gold dust, applied on a piece of wash-leather. This when highly varnished has a very splendid effect. Ladies' work-boxes, work-tables, &c., are frequently ornamented with engravings or drawings transferred to the japan work. For this purpose the engraving

is printed, or the drawing made on fine paper which has been previously prepared with a coat of isinglass or gum water. This, when dry, is applied with its face downwards upon the japan ground, covered with a thin coat of copal varnish; the paper is then moistened on the back with a sponge dipped in warm water, which soon dissolves the isinglass or gum, and the paper being loosened can then be taken away, leaving the print on the work. Or a print may be executed on an elastic composition of glue, &c., which receives the impression as well as paper, and may be immediately laid down upon the japanned surface, which will thus receive a perfect impression. All the processes connected with japanning require so much drying between them, that it is very desirable to hasten the work by means of stoves.

Common articles of furniture, such as dressing-tables, chairs, washstands, &c. are frequently said to be japanned, implying a greater durability than ordinary wood-painting; but the chief difference seems to be that the colours employed in painting them have been mixed with turpentine instead of oil.

JASPER. A handsome stone for inlaid work, which admits of a high polish, but is not used as a gem. It is a siliceous rock, containing, according to Beudant, silica 93·57 per cent., peroxide of iron 3·98, alumina 0·31, lime 1·05, water 1·09. It is coloured red by the peroxide, and yellow or brown by the hydrate of iron. It also occurs of green and other shades. When striped with green, yellow, red, or brown, it is called *riband jasper.* When these colours are in irregular concentric zones, it is called *Egyptian jasper.* Another variety is called *ruin jasper,* when a variety of brown markings appear on a dark ground. Jasper is nearly equal to agate in point of hardness, and is subject to the same treatment as carnelian in the lapidary's art.

JET. A variety of bituminous mineral coal, harder than cannel coal, of a deeper black colour, and possessing a higher lustre. It receives a brilliant polish, and is worked in the same manner as alabaster. In jewellery, the use of jet in mourning ornaments is very considerable. Jet is found at Whitby, Scarborough, and Yarmouth, and is also imported from Turkey. It can be turned with most of the ordinary tools, and worked with files and saws. Before the polishing, it appears of a brown colour, but after that process, it attains a beautiful and brilliant black. See Coal.

JET D'EAU. See Artesian Springs.

JEWELLING OF WATCHES. The frame-plates and other parts of watches are perforated by the watch-finisher, or escapement-maker, for the watch-jeweller, whose business it is to fit into the holes thus made certain hard stones, such as rubies, sapphires, chrysolites, and in some cases, diamonds, so perforated that the pivots of the watch movement may work in them. Diamonds are chiefly prepared in Holland, but all other hard stones are ground, polished, turned, drilled, and set by the watch-jeweller. Diamond powder (*bort*), embedded in small copper disks or mills, is the material used for grinding and polishing; and a fragment of bort set in a handle (as explained under Carbon, where different forms of diamond tools are figured,) is used for turning and drilling. A steel tool with diamond powder and oil is also used for drilling. Rapid motion is given by a lathe, with a large foot-wheel, so as to give the mandril from 6,000 or 7,000 up to 20,000 revolutions per minute, the latter speed being given for polishing only. The stone is ground by taking it on the end of one of the fingers of the right hand, and applying it to the surface of the bort mill, which is kept constantly wet with water applied by the fingers of the left hand: in a few seconds a flat surface is produced on a stone of the most irregular form; the flat surface is then placed next the finger, and a similar surface is produced parallel to the former, until the stone is of the thickness required: it is then placed, by means of cement, on a small chuck in the lathe, and turned with a bort tool into the proper shape for setting: the hole is then drilled, first, about half way through, when the stone is reversed, and the drilling completed from the opposite side; a precaution necessary to prevent fracture. The hole is also turned with a countersink, to receive the oil required for the lubrication of the pivot. The polishing is performed by hollowing out one end of a piece of brass, so as to fit the hollow of the stone, and with diamond powder therein, working it about in every possible direction, by pressing the finger against the other end of the brass. The stone is then detached from the lathe, and its flat surfaces polished by the rapid motion of the hand on a piece of plate-glass charged with diamond powder and oil.

Stones may be perforated so that the shoulder of the axis be supported by them; or in such a way, that the axis may pass completely through them, in which case an *end-piece* is required for supporting the end of the pivot. The latter method is adopted where the pivot is in rapid motion, and has a considerable weight to sustain, as in the case of the pivots at each end of the axis of the balance.

Fig. 1259 is a section, on an enlarged scale, of the jewelled pivot-hole for the axis of the balance of a chronometer. *a* is the hardened steel pivot, which is turned with a fine cylindrical neck, and made convex at the end. *b* is the drilled jewel, and above it, the

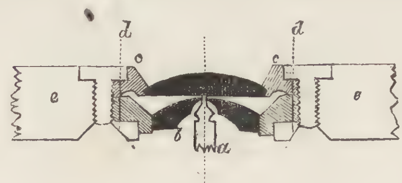


Fig. 1259.

end-piece. *b* is turned convex above, and concave beneath, of two different sweeps, to make it very thin at the point where it is drilled, and it is made a little smaller in the middle, to lessen the surface bearing. The end-stone is in the form of a plano-convex lens: it is generally a ruby, but in some cases, a diamond, cut into facets. The very small distance between the two stones allows the oil to be retained by capillary attraction. Each stone is burnished into a brass or

steel ring, in a manner similar to that in which glasses are set in telescopes, by turning a place to receive the stone, and leaving a fine edge of brass, which is rubbed over the edge of the stone with a burnisher. A diamond end-piece is usually set in steel, into which it is brazed; after which, the steel is turned into shape, polished, and blued. The stones are inlaid in a counter sunk recess, *c d*, in the side plate, or other part of the watch, and retained therein by two side screws, as shown in the figure.

The jewelling of watches is very minute and delicate work, as will be understood from the statement of the dimensions of the parts of Fig. 1259: the side plate *e e* is $\frac{1}{10}$ inch in thickness: the rings from *c* to *d* $\frac{1}{8}$ inch in diameter, and the pivot $\frac{1}{100}$ inch in diameter. In some of the flat Geneva watches, these dimensions are greatly reduced.

JOINERY. See CARPENTRY.

JOISTS. See CARPENTRY.

JOURNALS. See GUDGEONS.

KALI. The name of a maritime plant, the ashes of which furnish soda. From the name of this plant, with the Arabic article *al*, is derived the name of a class of substances of great importance in the arts. [See ALKALI.] The term kali was formerly applied to the alkali potash, the chemical symbol of which, K, is the initial letter of kalium.

KAOLIN. See CLAY, also INTRODUCTORY ESSAY, p. lxxxiv.

KELP. The ash remaining after burning sea-weed, for the purpose of obtaining carbonate of soda from it. See SODIUM, IODINE.

KERMES. Two substances of totally different properties are known by this name; the one, *kermes mineral*, is the golden sulphuret of antimony, [see ANTIMONY,] the other, *kermes grains*, a red dye stuff, consisting of the dried bodies of the female insects of the species *coccus ilicis*, and found upon the leaves of the *quercus ilex*, or prickly oak. The word *kermes* signifies in Arabic *little worm;* hence, this dye was called *vermiculus* in Latin, and *vermilion* in French, a term now applied to the red sulphuret of mercury. Kermes was formerly known as *German cochineal*. The rural serfs of Germany were bound to deliver every year to the convents, a certain quantity of kermes: it was collected from the trees upon St. John's day, between 11 o'clock and noon, with certain religious ceremonies, and was hence called *Johannisblut*, or St. John's blood. After the discovery of America, cochineal gradually superseded kermes for all brilliant red dyes. Lac dye is also an advantageous substitute; but at the present day, the Turks, Armenians, and Cossacks dye with kermes their morocco leather, cloth, silk, horse hair, &c. The red caps of the Levant are dyed with equal parts kermes and madder. Scarlet and crimson dyed with kermes were called *grain colours*, and were supposed to be more durable than cochineal colours, as the old Brussels tapestry may show.

The colouring matter of kermes is soluble in water and alcohol: it becomes yellowish or brownish with acids, and violet or crimson with alkalis. Sulphate of iron blackens it; it dyes a blood red with alum; an agate grey with copperas; with copperas and tartar a lively grey; with sulphate of copper and tartar a lively green; with tartar and salt of tin, a lively cinnamon yellow; with a larger proportion of alum and tartar, a lilac; with sulphate of zinc and tartar, a violet.

Kermes should be plump, of a deep red colour, with an agreeable smell, and a rough pungent taste.

KERSEYMERE. See WOOL.

KILLAS. See Introductory Essay, p. lxxxviii. *note*.

KILN, a name applied to various forms of close furnaces, differently arranged according to the purposes for which they are intended. Different kilns are described under BRICK, LIMESTONE, POTTERY, &c. A *malt kiln* is described under BEER; and it has been supposed that the operation of *killing* or *quelling* the vegetation of the moistened barley by heat, has given the name of *kill* or *kiln* to the hot chamber in which it was performed, and hence also to other enclosed heated places.

KING'S YELLOW, a pigment, the basis of which is orpiment or yellow sulphuret of arsenic (AsS_3). See ARSENIC.

KINIC ACID, an acid contained in the different species of cinchona or Peruvian barks, in combination with lime. It is also named *cinchonic* or *quinic* acid. Kinate of lime is found in the solution from which the bark alkalis have been separated, and the acid is extracted by decomposing the lime salt by dilute sulphuric acid. The clear solution, on being evaporated, deposits large distinct crystals of kinic acid, which resemble those of tartaric acid. Kinic acid is soluble in 2 parts water, and contains $C_{14}H_{11}O_{11}$, HO.

When kinic acid is treated with sulphuric acid and peroxide of manganese, it furnishes a very volatile substance, termed *chinone*, the vapour of which is very irritating to the eyes. It contains $C_{25}H_8O_8$. The odour of chinone is so distinct, that it enables us to detect the presence of kinic acid, and thus serves as a means of distinguishing true from spurious barks. According to Stenhouse, "to examine a bark for kinic acid, all that is necessary is to boil a little of it with slight excess of lime, to pour off and concentrate the liquor, introduce it into a retort, and distil it with a mixture of half its weight of sulphuric acid, and of peroxide of manganese. If the bark contain the smallest quantity of kinic acid, the first portion of the liquor which distils over has a yellow colour, and the very peculiar smell of chinone." Less than $\frac{1}{4}$ ounce of bark is sufficient for the experiment: the distillation need not be continued long, on account of the great volatility of the chinone. Two ounces of false bark (*China nova Surinamensis*), treated in this way, gave no indications of kinic acid.[1]

KINO, an extractive matter, the concrete juice of one or more plants growing in the East and West Indies, Africa, New Holland, &c. It is of a reddish brown colour, has a bitter styptic taste, and consists chiefly of tannine.

(1) "Memoirs of the Chemical Society," vol. ii.

KNIVES. See CUTLERY.

KREOSOTE, (from κρέας, flesh, and σώζω, I preserve.) This interesting product is obtained by distilling wood tar. It is remarkable for its antiseptic power. A piece of flesh steeped in a very dilute solution, dries up, but does not putrefy. The great efficacy of impure wood vinegar in preserving provisions, is due to the kreosote contained in it, and the effect of wood-smoke in curing and preserving salted meat and other provisions, is due to the same cause.

Kreosote exists abundantly in the heavy oil of beech-tar, as supplied by the wood-vinegar maker, and is procured therefrom by a tedious series of operations, which are described by Dumas in the 5th vol. of his "Chimie appliquée, &c." The distillation is conducted in a metallic vessel, and the different products collected apart. The most volatile portion, which is lighter than water, is rejected, but the second and denser portion, containing the kreosote, is agitated with carbonate of potash, to remove any adhering acid. This denser portion is then separated, and redistilled. The first portion that comes over is again rejected. It is then briskly agitated with a solution of phosphoric acid, and again distilled, whereby ammonia is separated. It is next dissolved in a solution of caustic potash of specific gravity 1·12, and decanted from the insoluble oil which floats on the surface. This alkaline liquid is boiled, and left some time in contact with the air, by which it acquires a brown colour. Sulphuric acid is next added to separate the alkali. The kreosote is again dissolved in caustic potash, boiled in the air, and the solution decomposed by acid, and this treatment is repeated until the product ceases to be coloured by exposure to air, and to the alkali. Much of the kreosote of commerce, however, turns brown by exposure, showing that it is not quite pure. It is, lastly, well washed with water, and distilled from a little hydrate of potash. The first portion that comes over contains water: the after product is pure kreosote. In this condition it is a colourless, somewhat viscid oily liquid, of great refractive and dispersive power. It has a penetrating peculiar odour, resembling that of smoked meat. It is most painfully pungent when applied to the tongue in small quantities. Its density is 1·037; its boiling point 397° Fahr. According to Ettling, it consists of 77·42 carbon, 8·12 hydrogen, and 14·46 oxygen, but its exact composition cannot be said to be settled. It is not readily ignited, and it burns with a smoky light. When mixed with cold water two solutions result, one consisting of 1·25 kreosote + 100 water; the other of 100 kreosote + 10 water. The aqueous solution is neither acid nor alkaline. Hot water dissolves a little more kreosote than cold, but the excess is again liberated on cooling. Kreosote absorbs moisture from the air. It dissolves readily in acetic acid: alcohol and ether mix with it in all proportions. Caustic potash dissolves in it, forming a crystalline pearly compound. It dissolves the resins, camphor, the essential oils, and most colouring matters. It immediately coagulates egg albumen, although much diluted.

Mr. Fitch has patented a process for impregnating salt with the more volatile products of wood-tar. The salt thus prepared is doubly preservative, and meat to which it is applied, is at once smoked and salted. Tongues and hams may be effectually cured by immersing them for 24 hours in a mixture of 1 part pure kreosote, and 100 parts of water or brine: the resulting flavour is said to be very delicate. Kreosote is medicinally employed in toothache, for dressing ulcers, and for external application in cutaneous diseases. It is also used to check hæmorrhage, and internally as a stimulant, and for the prevention of nausea and vomiting. It also prevents mouldiness in ink.

LAC, a resinous substance found on several different kinds of trees in the East Indies, and produced by the punctures of an insect (*coccus lacca*), and by its formation of the exuding juice into cells for its eggs. These adhere to the branches in grains, completely encrusting them, and are either imported in that form, and called *stick-lac*, or the grains are gathered from the branches, their colouring matter extracted, and formed into flat cakes, still preserving the granular appearance, and called *seed-lac*, or the seed-lac is melted up into masses, and called *lump-lac*. Finally there is *shell-lac*, which is seed-lac further purified by being put in bags of fine linen, and melted over a charcoal fire until it passes through them. The bags are squeezed, and passed over a smooth surface of wood, on which the lac is deposited in thin layers. If pure this kind of lac will take fire on a hot iron, and burn with a powerful smell. The heat of a ship's hold will sometimes run it into a solid mass, and thus diminish its value. The chief consumption of lac in Europe is for the manufacture of sealing-wax and varnishes. In India the inferior kind is made into bangles or armlets for women of the lower classes, the superior is fashioned into rings, beads, and other trinkets; and to fit it for such purposes, the natives purify it by melting in the manner above described. When the lac begins to exude, it is scraped off, and the bags are twisted or wrung by means of cross-sticks at their ends, to force out the melted contents.

The Indians make a good varnish of lac, coloured with cinnabar or some other pigment, with which they varnish boxes, cabinets, and other articles. Coloured varnishes of this description are much used in the adornment of their religious houses. They also employ lac as a dye. By pouring warm water on stick-lac a crimson colouring matter is obtained, which is made into square cakes for sale, and called *lac dye*, *lac lake*, or *cake lake*. These cakes when broken are dark-coloured, shining, and compact, but when scraped they yield a bright red powder approaching carmine. A mixture of lac, alum, and tamarind-water is the native dye for silk or cotton cloth of a crimson colour. The Indian lapidaries make use of lac as a vehicle for retaining the hard powders used in cutting and polishing gems.

The Indian corundum wheels are described under Emery.

The dye above referred to, and which constitutes much of the value of lac, is due to the insect which makes the cells, and which is of the same family as the cochineal insect. The parent lac insect, after laying her eggs, becomes a mere lifeless bag, of an oval shape, containing a small quantity of a beautiful red liquid. The young insects feed on this liquid, and their bodies assume the same hue, so that the branch which bears them appears to be covered with red powder. The cells of gum-lac which shelter them are more or less deeply tinged with the same colour. The best time for gathering stick-lac, so as to secure the colouring matter, is before the insects have made their escape.

Previous to the discovery of the true cochineal, the colouring matter of the lac insect was universally employed for dyeing red. The crimsons of Greece and Rome, and the imperishable reds of the Brussels and Flemish schools, were obtained from this source. The best quality of stick-lac is obtained from Siam; the twigs being frequently encrusted all round to the depth of a quarter of an inch, while sometimes a great accumulation takes place on one spot, as shown in Fig. 1261: that of Assam ranks next: the stick-lac of Bengal is inferior to these, being scanty and irregular in its coating of resinous matter. So abundant is the supply of lac among the uncultivated mountains of India, that it is asserted a consumption ten times greater than the present might be readily supplied. The accumulation of insects is so great, that the trees, often a species of *ficus*, on which they live, are exhausted and injured by this vermin.

Fig. 1260.

Fig. 1261.

After the dye is extracted, the gum-lac still requires much purification before it can be used for the more delicate varnishes. It was long a desideratum to render lac colourless, its dark brown hue being a drawback to its use as a spirit varnish. A premium of thirty guineas and a gold medal were offered by the Society of Arts for "a varnish made from shell or seed lac, equally hard, and as fit for use in the arts" as that prepared from any other substance. These were claimed by two persons, Mr. Field and Mr. Luning; and as both their processes were found to answer the desired end, a premium of twenty guineas was awarded to each. See Varnishes.

LACE. See Weaving.

LACKER, or LACQUER, a varnish either for wood or for brass, made with shell-lac and spirits of wine. That for wood, called *hardwood* lacker, may be in the proportion of 2 lbs. of lac to the gallon. Another recipe is 1 lb. of seed-lac and 1 lb. of white rosin to a gallon of spirits of wine. For brass the proportions are $\frac{1}{2}$ lb. of pale shell-lac to 1 gallon of spirit. It should be made without heat, but simply by agitation for five or six hours. It should then be left until the thicker portions have subsided, when the clear lacker must be poured off, or if not sufficiently clear, it must be filtered through paper. It darkens by exposure to light, so that paper should be pasted round the bottle to exclude it. A pale yellow lacker may be prepared from 1 oz. of gamboge and 2 oz. of Cape aloes, powdered and mixed with 1 lb. of shell-lac. For a full yellow, $\frac{1}{2}$ lb. turmeric and 2 oz. of gamboge; for a red lacker, $\frac{1}{2}$ lb. of dragon's-blood and 1 lb. of annotto. The colour, however, is modified by that of the lac employed. Lackers may also be coloured by dissolving the colouring matters in spirits of wine, and adding the proper proportions of these to the pale lacker according to the tint required. Mr. A. Ross prepares lacker with 4 oz. of shell-lac and $\frac{1}{4}$ oz. of gamboge, dissolved by agitation in 24 ounces of pyroacetic ether. The clear liquor is decanted, and when required for use is mixed with eight times its volume of spirits of wine.

Hardwood lacker is applied nearly in the same manner as French Polish. In lackering brass, the work must be cleansed from grease and oil, and if convenient, heated to the temperature of boiling water, when the spirit evaporates, and the varnish attaches itself more firmly to the metal, producing a brilliant effect. If heat cannot be applied, the air should be dry and warm. The lackering should follow immediately after the work is polished, otherwise it will become tarnished, and prevent the lacker from adhering. To prevent this tarnish, the work may be smeared over with oil, or kept under the surface of pure water, or wrapped closely up in cloths. Before lackering, the oil must be carefully cleaned off with *moslings*,[1] and afterwards with whitening applied with a rag or a brush. In brasswork factories, a *lackering-stove*, with a broad, flat top, is used for holding the articles which are to be heated preparatory to lackering; or a metal plate, supported by four legs like a table, and heated by a ring of gas-jets below, may be used. Brass tubes may be heated for lackering by being filled with boiling water, the ends being stopped with corks. In lackering the heads of a large number of small screws, they may be inserted in a piece of card, and heated over a charcoal fire or a gas flame, and the whole be lackered at one process. In thin circular works, the friction of polishing gives the heat required for the process. The lacker must be laid on quickly and uniformly by means of a camel's-hair brush; and as soon as one coat is applied, another must be put on, heat being used between the two coats if necessary. Circular works may be lackered

(1) The thin shreds or shavings of leather, shaved off by the currier in dressing cow or calf skins. They are as bibulous as blotting-paper, and well adapted to remove grease.

in the lathe. After the lacker is applied polishing completes the process.

LACTIC ACID. When azotized albuminous substances begin to decay, they possess the property of inducing an acid fermentation in sugar, whereby it is converted into lactic acid. The azotized matter of malt, the gluten of grain, wheat flour made into a paste with water, if left for a few days in a warm situation, become converted into lactic acid ferments. In a more advanced stage of putrefactive change, these substances act as alcohol-ferments or common yeast.

This acid was originally discovered in sour *milk*, whence the name. It may also be extracted from a variety of liquids containing decomposing organic matter, such as sauerkraut, the sour liquor of the starch-maker, &c. It consists of $C_6H_5O_5 + HO$; the water being basic, and capable of being replaced by a metallic oxide. The salts of this acid are termed *lactates*.

LACTOMETER, a kind of hydrometer for ascertaining the value of milk by noting its specific gravity; but as cream is lighter than milk, milk rich in cream and milk largely adulterated with water might furnish similar results, if the hydrometrical form of the instrument were used. Hence the better form of lactometer is a graduated glass tube, which is to be filled with new milk, and allowed to repose for a certain number of hours: then, by noting the thickness of the stratum of cream upon the surface, the per-centage of cream in the milk may be ascertained. When all the cream is skimmed from the milk, then the common lactometer will furnish the relative amounts of curd and whey: so that observations made by both instruments may furnish tolerably accurate results, the one for the butter value, and the other for the cheese value, of the milk under examination.

LAKES. See Alumina—Carmine.

LAMP, an arrangement for burning materials which are fluid at ordinary temperatures, in order to produce light. Such are the oils. Fats which are solid at common temperatures are usually made into candles.[1] The kind of oil used in different parts of the world for burning in lamps varies with the sources of supply, and these are numerous. In Great Britain, whale oil, boiled from the subcuticular fat of the whale, was long used, and still is to a certain extent, although the general introduction of coal-gas has lessened the demand for it. Oils obtained from seeds by pressure are used for artificial illumination in different parts of the world. In Paris, oil of rape-seed and oil of poppy-seed are clarified for lamps by filtration through cotton, wool, and other processes. In the south of France and in Italy an inferior kind of olive-oil is used, as also the oil of *arachis hypogœa*, or earth-nut. In Italy, lamp-oil is expressed from the stones of the grape. In Piedmont, walnut-oil is used; on the eastern and southern coasts of the Mediterranean and in China, oil of sesamum seed; and in tropical countries coco-nut oil (which at the temperature of Britain is a white solid like tallow): it is burnt in lamps made of the shell of the coco-nut and of bamboo. Much of the oil used in China is expressed from the seeds of a tree called *camellia oleifera*, cultivated for the purpose, as is also a shrub, *croton sebiferum*, from the fruit of which a solid oil is obtained by expression. Seal oil is used by the Esquimaux. The essential oils are too volatile for lamps. Petroleum and naphtha from fossil vegetable matter are used in localities which produce them. Naphtha, the most liquid of the oils, is also prepared by distilling fossil vegetable matter, and is well adapted for burning. In Genoa, the streets are lighted with naphtha from the adjacent territory of Amiano; and some years ago it was obtained by the distillation of pit coal, for the purpose of burning in the street-lamps of London. Alcohol, or spirits of wine, is chiefly used as a source of heat, on account of its clean flame, no soot being deposited.

A lamp differs from a candle in form rather than in effect; for although a candle is made of solid combustible matter, yet this must become fluid before it is available as a source of light. The upper part of a candle is formed by the heat of the flame into a cup of melted matter, which is drawn up to feed the flame by the capillary attraction of the twisted wick. In a lamp, the oil is drawn up in a similar manner, but certain provisions are required to separate the oil which is about to undergo combustion from the reservoir which is to continue the supply to the wick. One of the simplest methods of doing this is shown in that contrivance for a night-light, where a layer of oil upon the surface of water supports a small brass cup, at the bottom of which is a small piece of glass tube, fitted tight by means of cork. Before being ignited, the oil rises up the tube above the level on the outside; but when ignited at the top of the tube, the fluid is depressed by the heat. The tube is therefore fixed so far below the level of the oil that the greater pressure of the oil on the outside overcomes the depression within. The oil thus ignited continues to burn with a small feeble flame. If we attempt to increase the flame by enlarging the bore of the tube, the oil will not burn.

If, instead of this single capillary tube, we have a congeries of tubes, such as is presented by an ordinary wick, the lamp is greatly improved. The antique lamp, Fig. 1262, consisted of an extended open or closed vessel, with an unspun wick rising through a hole in the beak. With all its artistic beauty of

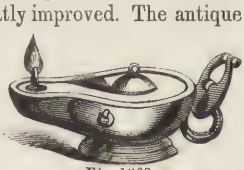


Fig. 1262.

form, such a lamp is not superior in construction to that with which the Esquimaux lignts and warms his snow-hut. The oil raised by the wick would vary in quantity with the supply in the lamp; combustion would take place only on the outside, where the air is in contact with the flame; and as the amount of carbon liberated from the oil is greater than can be appropriated by the oxygen immediately surrounding the flame, some of the carbon must escape unconsumed in the form of smoke. In such a lamp, the

(1) In the article Candle will be found a notice of the chemical constitution of oils and fats.

shadow cast by the flame considerably interferes with its illuminating power. The shadow may be diminished by bringing the flame forward away from the vessel. Thus the old kitchen lamp, Fig. 1263, has this advantage over the antique lamp, in having the beak removed from the oil vessel; and in proportion as the distance between the beak and the vessel is great, so the angle *b a c* becomes more acute, and consequently the shadow less.

Fig. 1263.

In the construction of the immense variety of lamps which are in use at the present time, great ingenuity has been displayed in the application of physical and chemical laws. The objects to be attained in good lamps are:—1. The production of such a form of wick that the quantity of oil decomposed by the heat, and the supply of air required for its combustion, may stand in such relation to each other, that the hydrogen and carbon of the decomposed oil may be consecutively consumed, and no smoke produced. 2. That the distance between the burning part of the wick and the surface of the oil be maintained as nearly constant as possible, so that the capillarity of the wick may be a nearly constant force, and the flame be thus supplied with the same quantity of oil all the time the lamp is in action. 3. That the reservoir of oil be so placed as to occasion as little shadow as possible. The use of the lamp must, however, regulate its form: thus, the shadow thrown by wall-lamps is unimportant, as the lamp covers the shadow; and in the study-lamp, as used by one person, the shadow is of little consequence, although at all times to be got rid of if possible. 4. To throw the light by means of collectors or reflectors from those parts where it is of little use into directions where it is most required.

Undoubtedly one of the greatest improvers of lamps is Ami Argand. His invention, in 1789, of the lamp which bears his name was an important step in the right direction. This invention consists of a burner formed of two metallic cylinders *c, d,* (Fig. 1264,) one within the other: the annular space between them, which is closed at the bottom, contains a cylindrical wick and a portion of the oil. The oil vessel *a v* surrounds the burner at some distance, and supplies this annular space with oil, by the tube *t,* the other tube *t′* being a counter support for the oil vessel. The inner cylinder is open at the top and bottom, so that by this arrangement the flame is surrounded by two concentric currents of air. This supply of air is not, however, sufficient for the perfect combustion of the oil as it is raised by the capillarity of the wick. If the wick be raised so as to increase the flame, much of the carbon of the oil passes off in the form of a dense smoke: if the wick be lowered, so as to adjust the flame to the supply of air, the flame is weak and the light deficient. By applying the principle of the chimney of a fire-place [see CHIMNEY] to that of the lamp, an artificial draught is excited; the oil is more perfectly consumed, greater heat is excited, and the heat becomes the motive power for the draught. At first, Argand used cylinders of sheet-iron arranged above the flame as the chimneys to his lamps; but the transparency of glass soon caused glass chimneys to be preferred. This chimney, supported on a rest outside the burner, included the inner and outer draught of air, and thus exerted a powerful influence on the velocity of both in proportion to its height. The protecting influence of the chimney was also shown in the remarkable steadiness imparted to the flame; for combustion not being checked by the cold air rushing in on all sides, but streaming up in a regulated manner through certain apertures, the flame was placed in the condition of a small furnace, in which combustion is rapid but perfect, and the heat and light great in proportion. The glass chimney was at first a simple straight cylinder, but this was found to supply too large an amount of air; some of that which passed through serving not to feed the flame, but only to cool it. This was remedied by contracting the diameter of the glass at a certain height above the burner, as at *b,* Fig. 1264, so as to form a shoulder against which the air should impinge, and thus be directed to the flame.[1]

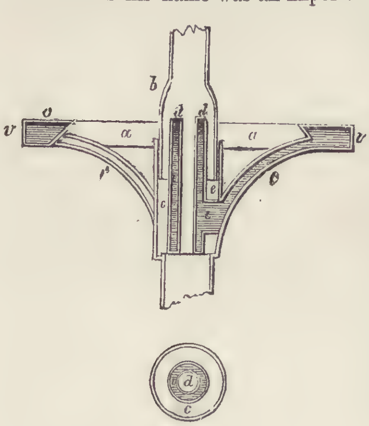


Fig. 1264.

The Argand burner, from its construction, could, of course, be applied to any form of lamp. It would evidently be a matter of great importance, so to arrange the oil reservoir that the sinking of the oil, consequent on its consumption, should have as little effect as possible on the light, and also that but little shadow should be produced. In what is called the *Astral lamp,* Fig. 1264, the oil is contained in a very flat annular vessel *v v,* so that a comparatively large supply of oil occupies only a small depth. This vessel surrounds the burner, at the distance of a few inches; it receives its supply of oil through a hole at *o;* the oil passes down the tube *t* into the annular space *d d,* and this being full, the oil may be poured into the vessel *v v,* until the level *o* corresponds with that of *d d.* Now the shadow produced by this oil-vessel will be small, but it will be cast all around; and the shadow of the supporting tube *t′*,

(1) This form of burner is represented at Fig. 1048, in our article GAS-LIGHTING, to which we must refer for further remarks on this subject. See also, for the structure of flame and the influence of the wick, the article CANDLE. The article FUEL may also be referred to in connexion with this subject.

and of the supporting and supplying tube *t*, will be cast as shadows on the table. When this lamp is used as a hanging-lamp, the shadow of its oil vessel will be cast more towards the ceiling than when it stands on the table.

In Phillips's *Sinumbra lamp*, or lamp without a shadow (*sine umbra*), the shadow if not destroyed is rendered imperceptible by the peculiar form given to the circular oil vessel, Fig. 1265. Its three surfaces meet in the form of a flat wedge, the sharp edge of which is directed towards the flame. The position of the flame with respect to the oil vessel is such that two tangents drawn from the apex and base of the flame to the oil vessel meet a few inches behind it in *x*, Fig. 1266; beyond this the vessel can cast no shadow, and even within the space where a shadow is cast, it is destroyed by the ground-glass shade, which rests upon the oil vessel, surrounds the chimney, and diffuses the light around. In this lamp the wick is moved by the following contrivance.

Fig. 1265.

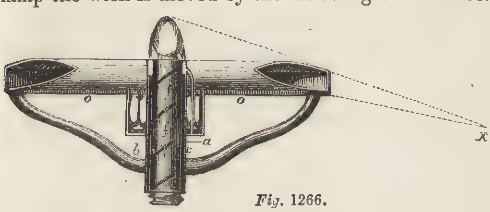


Fig. 1266.

The inner cylinder *f* has on its outer surface a deep, much inclined spiral groove, into which the short peg *a* of the wick-holder *e* fits. If the latter be turned on its axis the peg moves along the groove, and forces *e* up and down. *e* is turned by the cylinder *d*, which has a long slit in its side, into which a second peg *b*, on the outer side of *e*, fits. By this arrangement *d* can be moved freely up or down, taking with it the wick-holder, which is thus raised or depressed. In order that *d* may move easily it is firmly attached to the support for the chimney, and terminates at the upper part in a thick ring, which rests upon the edge of the cylinder *c*, which is made lower for the purpose, and thus the whole is brought up to the full height of the burner. The supports for the chimney are fixed in this ring, on turning which by the hand *d* is moved at the same time, and with it the wick.

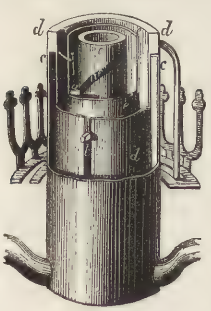


Fig. 1267.

In these contrivances the oil vessel is so situated as to interfere with the distribution of the light. In what are called *fountain reservoir* lamps, the oil vessel is removed to one side of the burner, so that its shadow may fall upon the wall, or to that side of the room where the light is least wanted. The oil vessel may consist of an ornamental globe or vase G, Fig. 1268, from the lower part of which proceeds a tube, the extremity of which is closed by a thumb-screw S. There is also a hole in the side of the tube, which can be opened or closed by depressing or raising the short cylinder *s* by its handle *h*. The globe is filled by pouring oil into the lower opening while the vessel is inverted and the hole closed. The screw is then put in, the vessel turned over and screwed into the neck of the oil cistern O. Now on depressing the handle *h* the oil will flow out, pass along the tube C, and ascend to the wick as far as the dotted line. As the oil is consumed by burning, and falls below the level of this line, air enters the oil cistern through the hole *x*, a bubble of air passes up through the hole, and a drop of oil falls out of the reservoir, thus maintaining the level marked by the dotted line. When the lamp is extinguished the handle *h* is drawn up, the hole is closed, and the supply of oil cut off. The arrows show the direction of the double current of air, and R is a cup for catching any oil that may overflow. For the sake of clearness, we will repeat in different terms the mechanism of the wick part as illustrated by this figure.

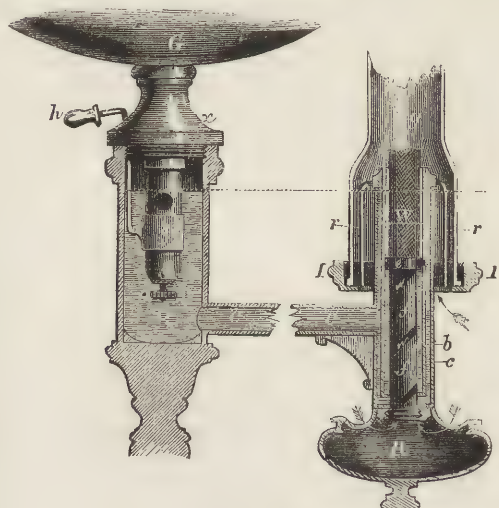


Fig. 1268.

W is the circular wick, fixed in the wick-holder *e*, which slides up and down on the tube *f*: a small tooth projecting on the inside of the ring *e* enters the spiral groove *w*, so that, on turning this ring round, it slides up and down the tube *f*, in the groove *w*, carrying the wick with it. To give motion to the ring *e* from the outside, a movable tube is placed within the tube *b* and *f*, and encloses the ring *e* within it. On one side of this tube a notch is cut from top to bottom, and a second tooth projecting from the outside of the ring enters this notch. The tube rises a little above the top of the external tube *b* of the burner, and has three small wires *r* fastened to it, which descend to the gallery I I, and are fixed thereto, so as to support it: the same wires also fit the interior of the glass chimney *g*, and prevent it from being upset. By turning the gallery I I round, the tube attached to it is made to turn round, and the pro-

jecting tooth of the ring *e* communicates motion to the ring also. At the same time, the interior tooth of the ring acting in the spiral groove, moves the ring *e*, and the wick up and down: the notch in the side of the tube which turns the ring allows it to rise or fall without imparting a similar motion to the tube, or to the gallery.

In order to get rid entirely of the shadow, lamps have been constructed in which the oil vessel is placed at the foot of the lamp, and raised by complicated apparatus depending partly upon hydrodynamic and hydrostatic laws, and also upon the operation of clockwork mechanism. In *Girard's* lamp the oil is raised in the same manner as is the water in a fire engine, viz. by the compression of air; or, as in Hero's fountain, in which the pressure exerted in a vessel is transferred to another distant vessel by means of compressed air, and is the means employed for forcing a liquid from its previous position in an upward direction. In *Keir's hydrostatic* lamp, oil is raised to the wick and sustained by a column of a solution of salt and water, of such density that it will support a column of oil $\frac{5}{4}$ds of its own height. Other heavy liquids have been applied in such lamps, such as syrup, honey, mercury, and a solution of sulphate of zinc. The latter is 1·57 times denser than oil, so that a column 10 inches high will support a column of oil 15·7 inches high. As the oil is consumed the column of zinc would sink to a corresponding level were it not that a reservoir of zinc solution gradually feeds the column, and thus maintains the oil to the proper level. Such a lamp has many advantages, but one fatal defect; it cannot be carried about, nor indeed moved, for a slight motion produces such fluctuations between the two fluids as to extinguish the light. In some descriptions of lamp, the oil is raised by a pumping apparatus placed with the oil at the bottom. Those *pump-lamps* in which the pump must be worked by hand at short intervals have all the defects of tallow candles which require snuffing. In *Carcel's clock-work* or *mechanical lamp* the oil is pumped up from the foot of the lamp by clock-work, and in such quantity as to exceed that consumed during the whole period of burning, the unconsumed portion flowing back to the foot over the outside of the burner. This overflow of the oil makes it necessary to screw up the wick higher than in common lamps, which has this advantage, that the flame being raised more above the edge of the burner where less heat is conducted from it, it burns more perfectly, no carbonaceous matter is produced on the wick and about the edge of the burner, which usually interferes so much with the regular flow of oil.

Carcel's lamp has been modified and improved by various lamp makers: but no one has succeeded in making it cheap. Attempts have been made to get rid of the expensive clock-work by introducing as the motive power a descending weight, such as a piston in a cylinder, or by causing a spring to act upon a piston; but in these cases the difficulty has been to regulate the accelerating force of the descending weight, or the diminishing force of the spring, so as to supply the burner uniformly. The method proposed has been to contract the ascending tube conically at a certain spot, into which a conical plug fits. The spring in rising enlarges the aperture at the contracted spot, while the sinking piston diminishes it by forcing the plug either backwards or forwards in proportion as their motion is irregular.

We must not, however, omit to notice a form of pressure lamp called the *Elliptic* lamp, patented by Mr. Meyer, in which these objections are for the most part removed. It is adapted to the combustion of crude vegetable oils, and answers the purpose perfectly, provided the user does not object to the trouble of regulating the mechanism—an objection which applies more or less to all mechanical lamps. In this lamp the oil is contained in the foot, in a cylindrical vessel, in which a leathern piston or valve is worked up and down by a rack and pinion. At the top of the solid stem of the lamp is fixed a strong spiral spring, which exerts a constant pressure on the piston, so long as it is above the bottom of the oil-vessel. Between the coils of this spring, and passing air-tight through the piston, is a tube which terminates in a funnel-shaped mouth in the oil vessel; this mouth is covered with a perforated dish for straining the oil. The oil is forced up this tube to the burner, on approaching which it receives a fine silver tube, several inches long and $\frac{1}{30}$th inch internal diameter, which is surrounded by a cup of wire gauze of tinned copper, for straining the oil of solid particles. The resistance offered by this narrow tube regulates the flow of oil, which would otherwise be forced up in a few minutes by the elastic force of the spring. The length and bore of the tube must be so proportioned to the force of the spring that enough oil shall be brought up to supply the flame with a certain additional quantity, which overflows, and thus keeps the metal parts of the wick cool. The overflowing portion returns to the reservoir at the foot. The lamp is filled with oil at a point above the spiral spring: it then flows down and rests on the top of the piston. Then by winding up the rack-work with a key, the piston is raised to the top of the cylindrical oil vessel; the ascension tube, with the burner attached, is then pushed down by hand through the piston, and the oil is thus brought into a position below the piston, and the spring in forcing the piston down raises the oil as before described. A lamp of this kind will yield an excellent light for 8 or 10 hours

In the above examples of lamps the oil vessel is placed *around* the flame, at the *side*, and also greatly *below* it in the foot of the pedestal. In Parker's *Economic* or *hot-oil lamp*, the oil vessel is placed *above* the flame; and the object is not only to throw the shadow in a direction where it cannot interfere injuriously with the light; but also to overcome the consistency of crude whale oil, which offers a great impediment to the capillarity of the wick at ordinary temperatures, so that it cannot be burnt in common lamps unless it be first made more fluid by heat. In the *hot-oil* lamp, the oil vessel R R, Fig. 1269, is composed of a double cylinder of metal surrounding the

upper part of the chimney, and curved slightly outwards, so as to reflect the heat upon the oil vessel; the hot oil then descends by the arm A to the burner.

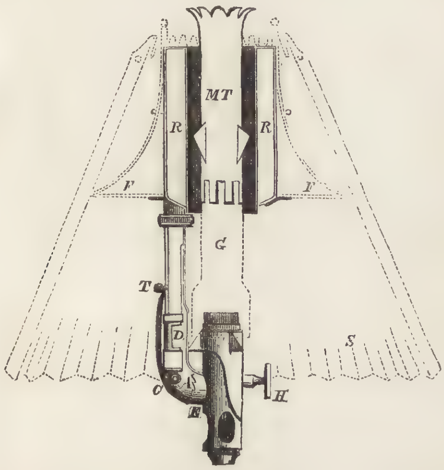


Fig. 1269.

The lower part of the arm, which is attached to the oil vessel, is furnished with a slide valve D, worked by a trigger T, so that the supply of oil can be cut off by raising the trigger, and the oil vessel removed from the lamp to be filled. The oil is introduced by this valve, the oil cistern being inverted, and this should be refilled each time the lamp is used. No air must be left in the vessel, because its expansion by the heat would cause the oil to overflow. The flame is regulated by raising or lowering the bell-mouthed glass chimney G, which rests upon 3 points below, and is moved by rack and pinion. The wick is not movable as in ordinary lamps, and a fresh wick, which is accurately cut by machinery for this lamp, must be inserted every time the lamp is used. A shade of glass or paper surrounds the whole of the *upper* part of the lamp.

It has been already stated, that volatile oils are not, in general, applicable as illuminating materials. This arises from the facility with which they liberate their carbon. They may, however, be brought into use by peculiar contrivances; either by greatly increasing the draught of air, or by mixing substances therewith which diminish the per-centage of carbon. In Berlin, for example, where oil of turpentine is cheap, it is mixed with four parts of alcohol, of at least 90 per cent. strength. This strength is necessary, for with a larger amount of water in the alcohol, the flame would be too much cooled, and the oil of turpentine be held imperfectly in solution. The carbon, originally amounting to 88 per cent., or eight times the quantity of hydrogen, is thus diminished to 63 per cent., or three times the hydrogen, which is a much less proportion of carbon than is contained in oil or tallow. The diminution of light from the same weight of spirit is compensated by the greater rapidity of combustion. The lamp for burning this spirit mixture is shown in section, Fig. 1270, in which A is the reservoir into which the burner B descends from above almost to the bottom. It consists of a straight, wide metal tube *a a*, fitting tightly into the real burner tube *u u*, which surrounds a loose cotton wick *o o*, and fastens it by the semicircular piece *x*. About two inches above A, the tube narrows into *d*, and terminates in the knob *c*, which is the real burner; at the base of *b* are 10 or 12 holes, $\frac{1}{4}$ line bore, arranged in a circle. When the lamp is to be used, common spirits of wine is ignited in the cup *e e*, to vaporize the spirit mixture in the upper part of the wick. The vapour which issues from *b* is then ignited, and forms the flames *f f*, which surround the knob *c*. The high temperature of the metallic mass is then sufficient to keep up the vaporization, and the lamp continues to burn without further trouble. To protect the reservoir A from the action of the burner as it becomes heated, the latter is surrounded to the depth of three inches with a wide case *i i*, so that a space filled with air surrounds it thus far. The light is brilliant but expensive.[1]

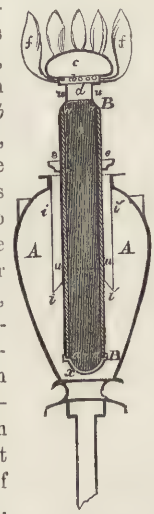


Fig. 1270.

Lamps without wicks have also been contrived for burning naphtha. In Beale's *steam and vapour* lamp, a current of air traverses the naphtha, and becomes saturated with it. This lamp produces a flame from six to seven inches high, when supported by a double current of air. In D'Hanen's lamp, the flame proceeds from a knob surrounded by ten holes, as in Lüdersdorff's lamp, Fig. 1270. Both lamps produce dazzling white flames, without smell; but the odour of the coal tar from which the naphtha is distilled is perceptible for a short time after they have been extinguished.

Camphine lamps have been used in this country. Camphine is obtained by distilling oil of turpentine over chloride of calcium, so as to free it from water. It then contains 88·46 per cent. of carbon, and 11·54 of hydrogen, or $C_{10}H_8$. It thus evidently becomes a powerful illuminating body, if properly supplied with air for the complete combustion of its ingredients; but from the ease with which it is decomposed, much nicety is required in adjusting the conditions under which it is consumed. If these fail, large flakes of soot escape unconsumed, and cover everything in the room with a kind of black snow. Or if the camphine be not pure, a strong smell of turpentine is evolved, producing headache and other disagreeable sensations. Mr. Young has invented an ingenious form of camphine lamp; and so also has

(1) In 1850, Mr. Marbe of Birmingham took out a patent for the manufacture of a fluid suitable for illuminations. from hydrocarbons, alcohol, and pyroxylic spirit, &c., purified and treated with acids, lime, alkaline, and various other substances, and distilled together. Also for a variety of lamps, adapted to the com bustion of such illuminating fluid. The principle is similar to that stated above. The same remark also applies to Brooke's patent, 1849, and to several others.

Mr. Roberts, who calls it a *Gem* lamp. The light is very white and brilliant.

For some further particulars respecting lamps, we must refer to LIGHT-HOUSE, and for a comparison of the illuminative values of candle, lamp, and gas-flames, we refer to the article PHOTOMETER.

LAMP-BLACK. See CARBON, vol. i. p. 315.

LAPIDARY WORK. (*Lapidarius*, pertaining to stones, from *Lapis*, a stone.) The art of the lapidary does not include the various modes of working or finishing stones, as its derivation would seem to imply, but is restricted to the cutting, grinding, and polishing of gems, small stones, &c., for jewellery, or for mineralogical specimens.

The stones cut by the lapidary are of various degrees of hardness,[1] and in cutting or polishing any particular stone, another harder stone is used, in the form of a powder applied to the edge or the surface of what are called *mills*, which are disks of metal and other materials, revolving horizontally on vertical spindles. Thus, the *slitting-mill*, the *roughing-mill*, the *smoothing-mill*, and the *polishing-mill*, are generally of metal; but for soft stones, the smoothing-mill may be a disk of willow wood or mahogany. The polishing-mill may be a spiral coil of list, the surface presented by the edges being the part used. Or wood covered with buff leather may be used.

The processes of the lapidary vary with the hardness of the stone. Taking *Alabaster* as the type of soft minerals, *Carnelian* as the type of minerals of medium hardness, and *Sapphire* as the type of hard minerals, three distinct groups may be formed in which the mode of treatment corresponds for all the members of each group.

(1) The following is the SCALE OF HARDNESS in minerals. In the examples selected, each mineral is scratched by that which follows it. The use of this scale is to determine the hardness of any given mineral by reference to the types here selected. Thus, suppose a body neither to scratch nor to be scratched by fluor spar, its hardness is represented by 4; but if it should scratch fluor spar, and not apatite, then its hardness is said to be from 4 to 5. The degrees of hardness are numbered from 1 to 10. The third column contains the names of some of the minerals, metals, and other substances of similar degrees of hardness; and the fourth column contains the number of minerals which in respect of hardness are ranked under each of the ten grades. The hardness of other minerals is represented in whole numbers and decimals:—

No. on the Scale of Hardness.	Types of Hardness.	Examples.	No. under each.
1.	Talc	Lead, Steatite or Soapstone, Meerschaum . .	23
2.	Compact Gypsum .	Tin, Ivory, Pot-stone, Figure-stone, Cannel Coal, Jet, &c.	90
3.	Calcareous spar, any cleaveable variety	Gold, Silver and Copper when pure; soft brass; Serpentine, Marble, Oriental Alabaster, &c. . .	71
4.	Fluor Spar, any cleaveable variety	Platinum, Gun-metal . .	53
5.	Apatite, in transparent crystals .	Soft Iron	43
6.	Felspar, cleaveable variety	Soft Steel, Porphyry, Glass	52
7.	Quartz, limpid and transparent. . .	Hardened Steel, Silex, Flint, Agate, Granite, Sandstone, Sand . . .	26
8.	Topaz	Hardest Steel	6
9.	Sapphire, or Corundum-stone . . .	Ruby and Corundum . .	1
10.	Diamond	Cuts all substances . .	1

ALABASTER. Hardness, 1·5 to 2.

Amber.	Jet.	Opal.
Cannel Coal.	Lava.	Pot-stone
Coral.	Malachite.	Satin-stone.
Enamels.	Mother of Pearl.	Steatite.
Glass.	Nacreous Shells.	Turquoise

CARNELIAN. Hardness, 7.

Agate.	Elvans.	Mina Nova.
Amethyst.	Emerald.	Onyx.
Aquamarine.	Felspar.	Opal.
Beryl.	Flint.	Pastes.
Blood-stone.	Fluor Spar.	Peridot.
Brazilian Topaz.	Garnet.	Plasma.
Carbuncle.	Granite.	Porphyry.
Cat's-eye.	Heliotrope.	Quartz.
Calcedony.	Jade.	Sard.
Chrysolite.	Jasper.	Sardonyx.
Chrysoprase.	Lapis Lazuli.	Serpentine.
Crystal.	Marble.	Topazes.

SAPPHIRE. Hardness, 9.

Mineralogists and Jewellers apply several names to the Sapphire, depending on its colour and lustre: namely,—

White Sapphire, when transparent or translucent.
Oriental Sapphire, when blue.
Oriental Amethyst, when violet-blue.
Oriental Topaz, when yellow.
Oriental Emerald, when green.
Oriental Ruby, when red.
Chatoyant, or Opalescent Sapphire, with pearly reflections
Girasol Sapphire, when transparent, and with a pale-reddish or pale-bluish reflection.
Asteria, or Star Sapphire, has six milk-white rays, radiating from the centre of a hexagonal prism, and placed at right angles to its sides. The Asteria is found in both the red and blue varieties of Sapphire, and is always cut so as to show the figures.

All the above Sapphires, the Chrysoberyl, the Zircon, and some other gems, are cut with diamond powder, and polished with rottenstone.

Fig. 1271 represents the lapidary's bench. It consists of a stout plank, about three feet six inches long, and one foot nine inches wide, supported on a frame about two feet six inches high. The top is divided into two unequal compartments, and a rim rises about

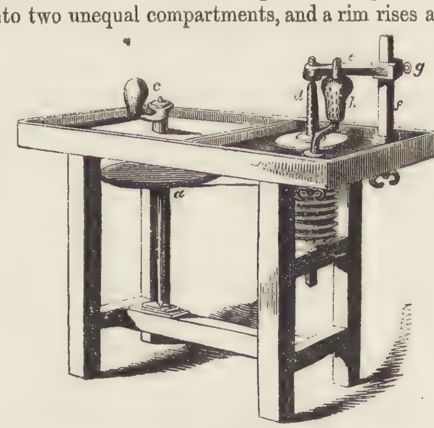


Fig. 1271.

two inches above the top, to catch the waste emery and water thrown off by the mill. In the left hand compartment is a hole and a collar, through which passes the vertical spindle of the driving wheel *a*, the lower conical end fitting in a rail of the frame. The driving wheel is about eighteen inches in diameter, and works just below the under surface of the bench top: it is worked by a horizontal handle *c*. In the right-hand compartment, the spindle *d* carries

the mill, which is about 8 or 9 inches diameter, and revolves about an inch above the surface of the bench: but it may be adjusted by means of a flange and screwed nut to a greater or less distance, according as the edge or side of the mill is required to be used. In the figure, the lower centre is a square wooden rod, passing through a mortice in a transverse rail of the frame, and kept to the desired height by a side wedge. By this contrivance, lap spindles of various lengths may be accommodated. The top end of the spindle also works in a wooden centre, screwed into a hole near the end of a horizontal iron arm *e*, which slides upon a perpendicular bar *f*, and is retained at the proper height by the binding screw *g*. The pulley is about 4 inches in diameter, and is fixed on the spindle just below the bench top. A little to the right, and in advance of the lap, is an iron support *h*, called a *gim-peg*, or *germ-peg*, about 8 inches high, and in the form of a crank: it is secured below the bench by a wing-nut, so as to allow the peg to be moved round to different distances from the lap, as may be required. Its use is to support the arm of the workman in grinding the edges of small stones, and also to serve as a guide for the vertical angle in cutting facets, for which purpose a wooden socket, shown in the figure, is slipped over the upper part of the rod, and held in its place by a wedge. Holes or notches, arranged round the sides of the socket, serve to determine the inclination of the stick upon which the stones to be cut are cemented.

In producing a plane surface upon an irregular piece of stone, as in smoothing a mineralogical specimen, if the natural surface be nearly flat, it may be at once applied to the flat surface of the roughing-mill; and if the stone be soft, such as a piece of pot-stone, a flat surface will be quickly formed; but if the natural surface be irregular, and the stone be hard, as a piece of blood-stone, or even an ordinary pebble, the process of grinding would be too tedious. *Splitting* or *cleavage* can seldom be adopted, since the stones wrought by the lapidary have not often a sufficiently lamellar structure to allow of plane surfaces being produced in this way. And besides this, flaws or veins might interfere with the surface. In most cases a plane surface is produced by cutting off a thin slice of the stone with the slitting-mill or slicer, which is a disk of thin sheet-iron, charged on the edge with diamond powder, and used as a circular saw for dividing all stones inferior in hardness to the diamond.

The use of diamond power is very general. Mr. Holtzapffel remarks, that "notwithstanding the apparent expense of the diamond powder, it is very generally employed, and is used for cutting nearly every Turkey oil-stone that is sold; and, although for this and some of the softer stones emery, or in some cases even sand, might be successfully employed, the diamond powder is almost exclusively used, as it is found to be the most economical, when the time occupied in the cutting is taken into account. The diamond powder cuts more rapidly than emery, and is very much more enduring: it also admits of being employed with very thin plates, and consequently the progress is also more expeditious on this account, and comparatively only a small thickness of material is wasted in the cutting. This is sometimes an important object with valuable stones, and the slicer is then made of small diameter, in order that it may be as thin as possible, and still retain the required degree of stiffness." Diamond powder is prepared from *bort*, [see CARBON, vol. i. p. 311,] from imperfect diamonds, and the fragments removed by the jeweller in splitting or cleavage. These fragments are crushed in a mortar, Fig. 1272, containing a deep cylindrical hole, terminating in the bottom in a spherical cavity of hardened steel, into which the pestle *b* accurately fits by grinding. This form of pestle and mortar is adopted to prevent the valuable dust from being scattered about; the cover *c* is added with a similar intention. When the diamonds have been put into the mortar, the pestle is thrust down, and struck a few blows with a light hammer, twisting it round after every blow. The crystalline structure of the diamond renders it brittle, and hence it is crushed without difficulty, although it stands alone and with the highest number on the scale of hardness.

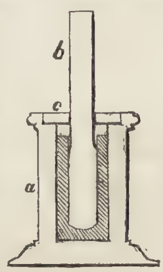


Fig. 1272.

If the powder be not crushed sufficiently fine, it is mixed with a little olive oil or oil of brick spread upon a flat piece of iron, such as an old laundry iron, and another small piece of iron is used as a muller. Oil of brick is generally preferred as the vehicle for the diamond powder. Its advantages are its limpidity, and its not being liable to thicken by exposure to the air.

The slicer is of sheet-iron 8 or 9 inches in diameter, and $\frac{1}{200}$th of an inch in thickness. In order that it may run in one plane, and not be distorted by the resistance of the work, it is planished or hammered into a slightly arched or disked form. This causes the edge to run true, and when it has cut a small depth into the stone, the trifling curvature of the disk gives way, and it is flattened by the groove it has cut, and in which it is compelled to run. The diamond powder, formed into a paste with oil of brick, is applied to the edge of the slicer with a small piece of stick or a slitted quill, and when uniformly distributed, the particles are fixed into the iron by gently pressing a piece of agate or flint against the edge. As soon as the diamond-dust begins to cut the stone, another part of the edge is operated on in a similar manner. Any particles of the powder which escape to the sides of the slicer, are wiped off with the finger, pushed to the edge, and pressed in with the charging-stone. With a new slicer, this *seasoning*, as it is called, must be performed a second time. When once properly seasoned, the slicer can be used for several hours, after which its cutting edge may be restored by a single application of the powder.

Before beginning the operation, the stone should be washed clean and dried, and the line of the

intended section marked with ink as a guide. The stone, held in the right hand, is applied lightly to the edge of the slicer, which is made to revolve with moderate velocity by turning the handle *c*, Fig. 1271, with the left hand. During the slitting, the slicer must be kept well supplied with oil of brick; and care must be taken to keep the cut in a straight line, the dished form of the slicer making it liable to cut upwards. A tolerably smooth surface, not an angle, ought first to be presented to the slicer, to prevent the diamond powder from being torn off. A moderate velocity and pressure are desirable to prevent the effects of heating. If the stone is too large and heavy for the hand, it is mounted on a crane, consisting of an upright rod moving between centres just in front of the perpendicular bar *f*, Fig. 1273, and upon this rod slides vertically a horizontal arm *j*, which is fixed to the rod at any height by means of a binding screw.

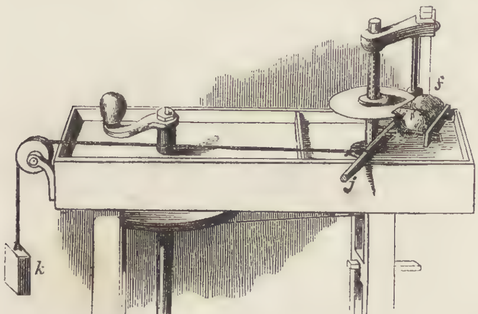


Fig. 1273.

The stone is fixed to the arm by a clamping piece and two binding screws, and is drawn forward by a weight *k* attached to a line leading from the extremity of the horizontal arm over a pulley. In this way the stone is kept up to the edge of the slicer, which the operator keeps in motion, and supplies with oil. For cutting parallel slices, the horizontal arm must be shifted after every cut.

The flat surfaces thus produced are ground upon the roughing-mill to remove the marks of the slitting-mill. The roughing-mill is a lead lap, and is kept supplied with emery and water. If the stones are too thin to be held by hand, they are cemented to a disk of wood with a handle of the same material. In charging the lap, the emery is rubbed into it with a smooth lump of emery-stone, or a piece of iron. The emery and water are then applied with a brush, and as the work proceeds, finer emery is used. The stone is applied flat to the surface of the mill, and pressed against it with moderate force.

When the stone has been sufficiently smoothed, it is polished on a lead or pewter mill well supplied with rottenstone and water; but as this fine powder will not adhere by simple pressure as the emery does, the face of the polishing-lap is *hacked* or *jarred* with the blade of an old table-knife, held near the middle between the thumb and finger, with the edge on the lap. On turning this round, the blade is made to vibrate or jump on the lap, and at each jump it produces a slight furrow. In this way the face of the mill is covered with minute lines or grooves, which serve to hold and retain the finely-powdered rotten stone.

If the stone is to be worked into a definite shape, such as an oval, a pattern is cut out in card, placed upon the stone, and its outline marked with ink upon it. The stone is then brought very nearly to the shape required by means of flat nippers of soft iron, which being firmly compressed upon the stone, and then twisted sideways, break off small particles. When by this contrivance the stone is brought nearly into shape, it is cemented upon a stick, the edge being left exposed, and is ground by holding the stick horizontally, at the same time constantly twisting it round. This will produce a square edge; but if a bevel or chamfer be required, the stick must be held at an angle, and twisted round as before. If a rounded edge be required, the stone is first prepared with a bevelled edge, and the angle is then removed by a rocking motion of the stone upon the flat mill. Rounded and elliptical faces are produced by peculiar rolling motions of the wrist, and it is surprising what accurate results are produced by working lapidaries by a cultivation of the sense of feeling. Stones that are flat on the back, and much rounded on the front, are called *tallow-tops*, from their resemblance to a drop of tallow. In cutting facets, the stone is applied to the mill as shown in Fig. 1274, the gim-peg being adjusted so that on inserting the end of the stick in one of the notches of the wooden socket the stick is inclined at the proper angle. All the different forms of facetting, which are numerous, are usually cut by practical lapidaries without any other guide.[1]

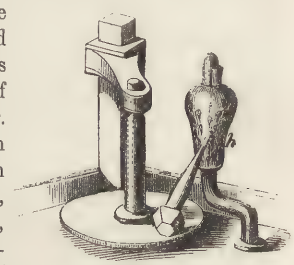


Fig. 1274.

Stones that are rounded to a cylindrical or conical form, such as a drop for an ear-ring, are cemented sideways upon a stick, and one half ground to the shape required. They are then detached from the stick, and cemented with the other side exposed. When this has been ground, the stone is successively cemented in two other positions at right angles to the first two, so as to connect the junctures of the two curved surfaces first produced. Stones that are to be ground into spheres for beads or the heads of pins, must also be cemented in at least four positions. The lap used for grinding flat surfaces is not used for rounded ones. The lap which is used becomes worn into numerous hollows of different sizes, some of which fit the curve of the stone under operation.[2] "Stones that are semi-transparent, such as garnets, are frequently left round on the face, or cut *en cabochon;* but such stones, if left of the full thick-

(1) In the 3d vol. of Holtzapffel's "Mechanical Manipulation," a minute account is given of the art of cutting facets. In our article CARBON, vol. i. p. 307, is a brief notice of the method of cutting and polishing diamonds.

(2) In the INTRODUCTORY ESSAY, p. cviii., is an account of the method of making agate beads as practised in India.

ness, would be too opaque to display much brilliancy; and therefore, with the view of increasing the transparency, garnets cut *en cabochen*, and called *carbuncles*, are generally hollowed on the under side, to make them thinner. The hollow on the under side is ground upon small spherical grinders of lead, called *balls*, made of various thicknesses and diameters, but mostly of the size of bullets. The balls are mounted upon a small conical spindle fitted to the lapidary's bench; the hole through the balls is also made slightly conical, so that they may be retained upon the spindle by the plain fitting, and allow of being readily detached for the substitution of other balls of different sizes. Similar balls made of pewter are employed for polishing."

The foregoing details will convey some idea of the lapidary's art. We shall have to treat of a somewhat kindred subject in our article SEAL ENGRAVING, and in noticing the gems and precious stones under their respective names, some details are given as to the methods of cutting and polishing them. Under GYPSUM, the method of cutting and polishing *alabaster* is described.

For the use of the amateur lapidary, Mr. Holtzapffel, has contrived an elegant and convenient apparatus, which is described in his admirable work already referred to, and may be inspected at the shop of his widow, 64, Charing Cross, and 127, Long Acre, London.

At Amsterdam, where most of the diamond cutting is performed, the steam-engine has recently been employed to give motion to the mills, by which means a great saving in labour is effected, and a very much greater speed produced. At the time this article is going to the press the celebrated Koh-i-noor (whose want of brilliancy excited general disappointment at the Great Exhibition) is being recut in London, under the superintendence of some artists from Amsterdam, in a more artistic manner, in order to enhance the brilliancy of this fine gem. The mill which operates upon it is made to rotate 2,400 times per minute.

LAPIS-LAZULI or LAZULITE. See ULTRAMARINE.

LATHE. See TURNING.—Also INTRODUCTORY ESSAY, p. cxxxvi.

LAVENDER, the name of hoary, narrow-leaved, fragrant bushes, with generally blue flowers, arranged in close terminal simple or branched spikes. Twelve species have been described, only two of which are of much interest, viz. the common lavender (*Lavandula vera*), and French lavender (*L. spica*). The former yields the fragrant *oil of lavender* used in perfumery, (its solution in spirits of wine forming what is called *lavender-water*,) and the latter *oil of spike*, used by painters on porcelain, and in the preparation of varnishes for artists. [See ESSENTIAL OILS.] English oil of lavender is most esteemed: it is prepared chiefly at Mitcham in Surrey, where the plant is extensively cultivated for the purpose. It is in highest perfection when about a year old. At first it is nearly colourless, but gradually acquires a pale amber tint. Oil of spike is chiefly imported from the South of Europe.

LEAD. The chemical symbol for lead is Pb, from *plumbum:* its equivalent number is 104, and its density 11·35.

SECTION I.—METALLURGICAL HISTORY OF LEAD.

Lead was well known to the ancients, and is frequently mentioned in our translation of the Bible, and in those cases where *tin* is mentioned it has been supposed that lead of some kind is meant. The Hebrew word *bedil* has been translated *tin;* which term the Greek translators of the sacred books rendered *κασσίτερος*; and this last word has been translated by more modern writers by *stannum.*

Beckmann, in his "History of Inventions," has a learned essay on the meaning of the three works *bedil*, *κασσίτερος*, and *stannum;* and although he does not settle the point, he does not dispute the fact that lead was in extensive use by the people of antiquity. Camden on the authority of Pliny says:—"In Britain, in the very upper crust of the ground, lead is dug up in such plenty, that a law was made on purpose to stint them to a set quantity." To what extent the lead ore was worked by the Britons, or by the people who visited them for the purposes of trade, is not known; but there is no doubt that under the government of the Romans the lead of Britain was an important article of commerce. Blocks or pigs of lead have been discovered with Latin inscriptions on them; and in the neighbourhood of the mines are to be traced the remains of Roman stations, houses, and burial-places. The Saxons after the departure of the Romans continued to work the lead mines, one of which near Castleton was dedicated to Odin. The mines near Wirksworth were wrought before the year 714, for we read of a sarcophagus of lead lined with linen having been prepared in this locality. In the year 835 the mines of "Wircesworth" were surrendered to one Humbert, on payment of an annual rent of lead to the value of 300 shillings for the use of Christ's Church, Canterbury. In Doomsday-book the mines in the Peak and in the wapentake of Wirksworth are referred to as the peculiar domain of the sovereign. In the records of the Duchy of Lancaster, the Derbyshire lead mines are designated as "The King's Field." The mines until a recent period were regulated by ancient laws and privileges, which empowered all persons to dig and search for veins of ore without being accountable to the owners of the soil for any damage done to the surface or even to growing crops. It is now held that unless a miner procures ore enough from any vein he may be in search of to *free* the same; that is, to pay to his farmer or lessee a dish of ore, he is liable to the owner for any damage committed in the search.

In the King's Field a mineral court is held under the presidency of a *bar-master*, who, assisted by a jury of 24 miners, decides all questions respecting the duties or *cope* payable to the king or his lessee: they also regulate the working of the mines by those to whom the bar-master has given possession; and in certain cases enforce the payment of debts incurred in working them. These laws, as Mr. Farey

remarks,[1] evidently originated in the very infancy of mining, and were adapted to the working of the mines entirely by manual labour. A person having found a vein of ore, made certain crosses on the ground, as a mark of temporary possession, and then informed the bar-master, who attended and received a dish of ore, the first produce of the mine, as the condition of permitting him to proceed in working his *meer* or measure of 29 yards in length of the vein. At the same time the bar-master took possession of the next adjoining 14½ yards or half-meer of the vein for the king. If the vein seemed promising, it often happened that other persons applied to be admitted, each to free his meer or 29 yards in length of the rake vein in succession. It was a condition that each person, or company, possessing their meer or meers in partnership, called *groove-fellows*, should immediately begin and continue to work at their mine; and in case of intermission for 3 successive weeks, the bar-master was authorized to dispossess them and give the mine to another.

The King's Field comprises the greater part of the mountain limestone district of Derbyshire. In the first meers or mines the limestone had no other cover than the soil. The miners worked with mattocks or picks, and with hammers and iron wedges in the harder veins, removing the ore, and throwing out the spar and rubbish on each side of the vein. Having worked the vein to a certain depth, they erected a square frame, composed of 4 narrow planks of wood placed across and pinned at the corners; on this frame 2 upright posts were erected with holes or notches to receive the spindle of a windlass for winding up the ore in small tubs. This apparatus, called a *stowse*, being erected on each meer, the working was continued to the depth of many yards; the heaps of rubbish meanwhile accumulating on each side many hundred yards in length, with other similar ditches and heaps from other meers crossing them in various directions. When the miners in this way had excavated as low down as their simple means permitted, or when the ore ceased to be profitable, the meer was abandoned; but as in after times other adventurers might appear and carry on the work, the poor farmer of the land thus disturbed was forbidden by strict laws from returning the barren rubbish into the deep and dangerous ditches thus excavated. Mr. Farey saw numbers of these ditches in the state in which they had been left by the miners, altered only by the treading of cattle and the natural mouldering of the sides. In some cases a better system was adopted. In rich mines, instead of throwing all the rubbish to the surface, it was thrown upon floors or stages of wood called *bunnings*, placed across the whole length of the mine except just under the stowses, at which places they sunk 6 or 8 feet lower; and after clearing some distance, erected other bunnings, under the former, on which the refuse was thrown as before. As the work proceeded, the shaft under the stowses was lined with timbers or stone; and the vein-stuff being thrown on the bunnings around it, a regular hill was at length formed called the *hillock*, or the *mine hillock*.

In the course of time the laws which required a working stowse to be used once in 3 weeks for drawing ore at each meer, became so far relaxed as to allow models of stowses, or small sham drawing apparatus, made of thin laths of wood which the bar-master provided, to be used as the means of keeping possession of all the meers but one on a consolidated mine; a custom which still prevails, and is so rigidly enforced, that a mine on which large steam engines may have been long used is not held to be legally occupied unless one of these pigmy memorials of the primitive mode of drawing ore is constantly kept "in sight of all men," as the law expresses it, and others on each of the meers of ground or lengths of 29 yards of which the mine consists. Persons detected in removing or destroying the bar-master's stowses, wherever or however inconveniently they may be placed, are liable to certain penalties. These models, to be effective, must have no nails in their structure, but be pinned together with wood as was the case with the original machines. If a known unoccupied vein cross a paddock, a garden, or a gentleman's park within the King's Field, it must be leased of the bar-master by the payment of a dish of ore, and the erection of these sham stowses, and even a real stowse, which must be worked periodically in however slight a manner. If this be omitted, any person on application to the bar-master may take possession of such vein, and destroy the land in pursuit of it. Such laws as these greatly interfere with the culture of the land, especially when it is considered that there are many veins of ore which are too narrow or too poor to be worked with profit; and yet to prevent needy adventurers from claiming them it was necessary to keep the land *stowsed* even on the barren hills of grit-stone rocks and the coal measures.

All lead ore which is dressed ready for sale in the King's Field is required to be measured in the presence of the bar-master before it is removed from the mine: for which purpose a rectangular box called a *dish* is used in the Low Peak. It is 28 inches long, 6 wide and 4 deep, and is reputed to hold 14 Winchester pints when level full. In the High Peak 16 pints are reckoned to the dish. In measuring the ore, every 25th dish is set aside by the bar-master as the King's *lot*, *cope*, or duty.

By an act passed in the 15th and 16th Victoria, the short title of which is "The Derbyshire Mining Customs and Mineral Courts Act, 1852," most of the inconvenient and absurd old customs so long complained of are modified or abolished. It is lawful by this act for all subjects of the realm to search for veins of lead ore, and dig mines in any kind of land, except in places for public worship, burial grounds, dwelling houses, orchards, gardens, pleasure grounds, and highways: but if no vein of ore be found, the land must be levelled and made good at the expense of the person making the search; and if ore be found, a proper recompense must be made to the occupier of the land for any damage done. The landowner has also

(1) "Survey of the Agricultural and Mineral Districts of Derbyshire." 3 vls. 1811, 1813, and 1817.

the power of removing and disposing of the *calk, feagh*, spar, and other minerals and rubbish, and even such as contains lead ore, if left for 18 months on the ground.

The dish or measure for measuring the ore is to contain 15 pints of water.

The bar-master, with two of the grand-jury, provide the miners a way either for foot passengers or carts from the highway lying most convenient to the mine, and also from the mine to the nearest running stream or spring of water; but the miners are not to defile the waters of running streams so as to render them injurious to cattle.

If any mine be left unwrought, and there be no reasonable excuse for such neglect, such as want of water, &c., the bar-master may direct the same to be forfeited, and in the presence of two or more of the grand-jury may give such mine to any person willing and able to work it.

This act contains a variety of other minute details for the regulation of the mining property of Derby, and also settles the constitution of the Barmote courts, defines the duties of the stewards, bar-masters, and other officers, and gives scales of fees, forms of proceedings, &c. &c.

In addition to those of Derbyshire, there are also lead mines in Allendale and other western parts of Northumberland;[1] at Alston Moor, &c., in Cumberland; in the western parts of Durham; in Swaledale, Arkendale, and other parts of Yorkshire; there are also mines in Salop; in Cornwall; the Mendip Hills in Somersetshire, and in the Isle of Man. The Welsh mines are chiefly situated in the counties of Flint, Cardigan, and Montgomery; those of Scotland in Ayr, Kirkcudbright, and Lanark; and those of Ireland in Wicklow, Waterford and Down.

The following table shows the produce of lead for five years in the above districts:—

	1845.	1846.	1847.	1848.	1849.
	tons.	tons.	tons.	tons.	tons.
Devon and Cornwall...	7,188	5,947	8,333	7,458	8,045
Northern Counties	28,820	27,621	28,387	28,893	30,781
Ireland	855	811	1,380	1,188	1,653
Scotland	901	942	822	1,736	957
South Wales	4,807	5,084	6,419	4,053	5,941
North Wales	6,207	4,943	5,875	7,069	7,448
Shropshire	2,500	3,200	3,000	2,800	2,310

Pig lead is worth about 16*l*. per ton. A few years ago it was calculated that of the 55,000 tons, which is about the average annual quantity of lead produced in Great Britain, about 25,000 tons yield 8 oz. per ton of silver, or 200,000 oz., which at 5*s*. per oz. is equal in value to 50,000*l*. a-year.

In 1849 our exports of lead were of the declared value of 287,737*l*., and in 1850, 387,575*l*. France takes the largest quantity; Holland, Russia, and the East Indies are our next best customers. The exports in the latter year were as follows:—

	Tons.	cwt.	qrs.	lbs.
Lead ore..................................	165	17	0	0
Pig and rolled lead	20,165	18	1	1
Shot	1,750	9	3	19
Litharge....................................	562	1	2	13
Red Lead	2,112	0	3	8
White Lead	2,043	17	2	4

(1) The lead mining district of Allenheads is more particularly noticed in our INTRODUCTORY ESSAY, p xcviii.

The lead mines of the United States of America have of late years become of great value and importance: they are for the most part situated in Illinois and the Wisconsin territory.

SECTION II.—LEAD AND ITS COMPOUNDS.

Lead is of a bluish-grey colour, and of a strong metallic lustre when the surface is clean, or recently cut; it is soft, and leaves a black streak on paper. It is flexible and non-elastic; it can be rolled into thin sheets, and drawn into wire, but it is inferior in tenacity to most of the other ductile metals. It fuses at about 612°, and when slowly cooled it forms imperfect octahedral crystals. It is volatile at a red heat, but not sufficiently so to admit of its being distilled. It contracts on cooling, but by being repeatedly heated and cooled it becomes permanently enlarged: this may be noticed in the case of a leaden wash-hand basin which is frequently made to contain hot water. In castings of lead which are rapidly cooled there is generally a cavity due to the contraction in cooling, which in rifle bullets is found to interfere with the rectilinear passage of the ball. Hence rifle balls are sometimes moulded out of rolled lead. The density of lead is said not to be increased by hammering, but the metal becomes hot under the hammer, and opens into fissures.

In distilled water, previously boiled to expel the air, and preserved in close vessels, lead undergoes no change; but in open vessels it soon becomes oxidized, and the carbonic acid of the air, combining with the oxide, produces minute, shining, brilliantly white crystalline scales of carbonate of the protoxide. If a minute portion of saline matter be present in the water, the oxidation of the lead is retarded, and some salts prevent it altogether. The preservative power of neutral salts appears to be due to the insolubility of the compound which their acid is capable of forming with lead. Thus phosphates, sulphates, chlorides, and iodides, are highly preservative; so small a quantity as $\frac{1}{30000}$th part of phosphate of soda, or iodide of potassium, in distilled water, preventing the corrosion of lead. In a preservative solution the metal gains weight during some weeks, as its surface becomes coated with carbonate, which is slowly decomposed by the saline matter of the solution, and the metallic surface being thus coated with an insoluble film, which adheres tenaciously, all further change ceases. In cases where danger is likely to arise from the use of lead pipes or cisterns, Dr. Christison recommends that they be first filled with a very weak solution of phosphate of soda, by which they will be covered with an insoluble protective film. Many kinds of spring water do not corrode lead, on account of the salts contained in them, and hence may be safely collected in leaden cisterns; but such cisterns should have wooden not leaden covers, because the vapour rising from the water in the cistern condensing upon the under surface of the cover, is pure distilled water, and will corrode lead. Another source of danger from lead arises from voltaic action, as where iron or copper bars, screws, or pipes, are in

contact with or soldered into lead, and it may be acted on by alkaline bases, or by acids, according to the electric state in which it may be thrown by the metal in contact. Pieces of mortar which have fallen by accident into leaden cisterns, will corrode and eat holes through them, the lime of the mortar oxidizing the metal, and assisting in the solution of the oxide. The use of leaden vessels frequently leads to the contamination of various articles by oxide of lead. Chevreul has detected lead in certain liquors kept in flint-glass bottles, and the dyer and calico printer is sometimes embarrassed by the presence of minute quantities of lead in his dye-stuffs, or in the water of his cisterns.

The most recent investigation of the action of soft water on lead is that by Messrs. Graham, Miller, and Hofmann, the more important results of which are stated in the Report "on the chemical quality of the supply of water to the Metropolis," (1851,) from which we abridge a few details. The corrosive action of the soft spring waters of Surrey was found to be very small, with the exception of the water from the Punchbowl at Hindhead, of which the power to dissolve lead was rather considerable. The former waters contained only a very small quantity of dissolved oxygen. River or spring water from the chalk strata, softened artificially to about 3° of hardness,[1] was found to have no dangerous action upon lead. The protective character of the sulphates did not appear to be uniform in its action; while some salts, such as chlorides, and more particularly nitrates, may increase the solvent action of water on lead. Of all protecting actions that of carbonate of lime dissolved in carbonic acid appeared to be the most considerable and certain. The effect of a very small quantity of carbonic acid was found to be very remarkable in neutralizing the usual solvent action which water exercises on lead through the agency of the dissolved oxygen. The soluble oxide of lead is converted into the carbonate, which although not absolutely insoluble, appears to be the least soluble of all the salts of lead. Pure water did not dissolve more than $\frac{1}{60}$th of a grain of carbonate of lead to the gallon of water, or one part of lead in 4 millions of water; while water which already contained as much as six grains per gallon of oxide of lead in solution, had the quantity of metal reduced to $\frac{1}{57}$th of a grain by free exposure to the atmosphere for twenty-four hours, the lead being deposited as carbonate of lead in consequence of the absorption of carbonic acid gas. These quantities also represent pretty closely the proportion of lead which was dissolved by water left in contact with the metal in a divided state for twenty-four hours; in one experiment distilled water was used, and in the other water containing three per cent. of its volume of carbonic acid. The pure water became highly poisonous, while that containing carbonic acid remained safe. Carbonic acid is usually present in well, lake, and river waters in sufficient quantity for protection, and the freedom of such waters from lead impregnation is ascribed rather to their carbonic acid than to the salts contained in them; for lead placed in distilled water which had been boiled to expel its carbonic acid is no longer sufficiently protected by the addition of the same salts. An excess of carbonic acid may render carbonate of lead soluble, as it does carbonate of lime, but not by any means to the same extent; moreover, this excess of carbonic acid is very unusual. The presence of organic matter, such as decaying leaves and impurities, is doubly dangerous, as the rapid corrosion which it occasions may be followed by solution of the lead salt formed when the carbonic acid is either deficient, as in rain water generally, or in excess.

Dr. John Smith of Aberdeen made some careful experiments to ascertain the action of the water of the Dee on the leaden pipes by which it is served. The water is under $1\frac{1}{2}$° of hardness, and is distributed by iron mains, and taken into the houses by leaden pipes, varying from 12 to 100 yards in length, to which leaden cisterns are attached. The supply is constant, and amounts to about one million gallons a day. In some instances no indication of the presence of lead in the water which had passed through the pipes was found; in others small quantities were discovered in solution; these varied from $\frac{1}{100}$th to about $\frac{1}{28}$th of a grain in a gallon of water. No injurious effects could be traced to the use of water containing this minute quantity of lead, and the commissioners conclude "that the danger from lead in town-supplies of water has been overrated, and that with a supply from the water companies not less frequent than daily, no danger is to be apprehended from the use of the present distributory apparatus, with any supply of moderately soft water which the metropolis is likely to obtain."

The lead of commerce is tolerably pure. It may be obtained pure by reducing in a crucible oxide of lead obtained by the decomposition of crystallized nitrate of lead. Hydrochloric acid, even when concentrated and boiling, acts but feebly on lead. Weak sulphuric acid does not act upon it when the air is excluded, but if heated in strong sulphuric acid, sulphate of lead is formed with evolution of sulphurous acid. Nitric acid oxidizes lead with rapidity, and forms with its oxide a nitrate which crystallizes on cooling in opaque octahedrons.

Chemists are acquainted with four oxides of lead, only one of which has basic properties. The *protoxide* PbO, also called *litharge* and *massicot*, may be prepared by heating the carbonate to dull redness. When pure it has a delicate straw-yellow colour; it is very heavy, and slightly soluble in water. It melts at a red heat, and in this state attacks silica with ease, penetrating an earthen crucible in a few minutes. Hence its use in the manufacture of flint glass. It forms salts with many of the acids. By exposing the protoxide for a long time to the air, at a temperature of between 570° and 580° the red oxide Pb_3O_4 is formed. It is known by the terms *minium* and *red lead*. It is used as a pigment, and as a substitute for vermilion. To obtain it of a brilliant colour it should be made in large quantities; but its brilliancy becomes

(1) This term is explained under FILTRATION, vol. i. p. 649.

dimmed by exposure to light. The most brilliant minium, called *orange mine*, is said to be obtained by heating and stirring in iron trays pure carbonate of lead in a current of air at a temperature a little under 600°.

In the ordinary manufacture of red lead a reverberatory furnace with a double hearth, one above the other, is used, in the lower of which the temperature is highest; here the metallic lead, which is used as pure as possible, is converted into massicot, care being taken to avoid the fusion of the oxide, for that would delay its conversion into minium. The massicot thus produced is usually levigated, washed and deposited, in order to get rid of particles of metallic lead: it is then placed on the upper hearth, which is heated by the waste heat of the lower one. It is spread in a thin layer on the hearth, and the surface is renewed from time to time by raking, or it is placed in shallow trays of sheet-iron, arranged upon the sole. In some cases a single furnace is worked by day for the conversion of the metallic lead into massicot: this is put in quantities of 50 lbs. into iron trays, which are piled up and exposed during the night to the residuary heat of the furnace, whereby the massicot absorbs more oxygen, and becomes partially converted into red lead. The operation must be repeated twice before the lead is of the proper colour.

The other two oxides of lead are the *peroxide* PbO_2, and the *suboxide* Pb_2O.

Sulphate and *phosphate* of lead also exist as ores. The *chromate* is found in small quantities; it is the *chrome yellow* of painters, and is prepared artificially by adding a solution of chromate of potash to a soluble salt of lead.

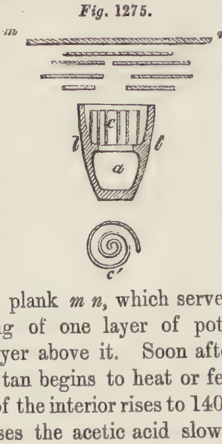
Native lead is rare; but specimens of it have been found associated with galena in the county of Kerry, Ireland, and in an argillaceous rock near Carthagena, in Spain. It has also been found at Alston Moor. Lead is usually found in combination with sulphur, but it also occurs with oxygen, selenium, arsenic, tellurium, and various acids. The ores of lead, with one exception (plumbo-resinite,) are fusible before the blowpipe; placed on charcoal with a little carbonate of soda as a flux, a fragment of an ore will yield a globule of metallic lead.

Native oxide of Lead occurs in small quantities as a pulverulent mineral of a bright red colour, sometimes mixed with yellow. *Chloride* of lead occurs in the Mendip Hills. The most important and abundant ore is the *sulphuret* or *galena*, which crystallizes in the cubic system, and is deposited on a matrix of quartz, carbonate of lime, fluor-spar, or baryta. The rich lead mines of the West of England occur in clay-slate; those of Derbyshire and other northern districts in limestone. Galena, when pure, is composed of lead 86·55, and sulphur 13·45. It nearly always contains silver, whence the name *argentiferous galena* applied to it. It is a valuable source of silver in many parts of Europe and America.

Carbonate of Lead is found in acicular crystals, in radiated and compact masses, in concretions and in earthy deposits: it has a white colour, and except in the earthy varieties, the peculiar lustre of white lead. The crystallized specimens are sometimes black from the presence of sulphuret. A specimen from Teesdale, analysed by Mr. J. A. Phillips, gave 83·55 of protoxide of lead, and 16·52 of carbonic acid. This gentleman says:—"When abundant, the carbonate forms a most valuable ore of lead, and frequently yields above 75 per cent. of that metal; but from its dissimilarity to the other ores of lead it was for a long time considered by miners to be of no value; large quantities which had been formerly buried in rubbish, are at the present time being excavated and worked with great advantage in many of the Spanish mines, as also at different points of the valley of the Mississippi, in the United States of America."[1]

Carbonate of lead, or *white lead*, PbO, CO^2, is manufactured in enormous quantities for the use of the painter. When pure it is a soft white powder of great density; it is insoluble in water, but readily dissolved by dilute nitric or acetic acid. The manufacture of white lead is for the most part conducted by the Dutch process, which was introduced into England about 1780. In this process metallic lead is cast into the form of stars or circular gratings, six or eight inches in diameter, and from ¼ to ½ inch in thickness: 5 or 6 of these are put into an earthern pot shaped something like a flower-pot, and containing a little strong acetic acid not in contact with the lead. The pots are arranged side by side on the floor of a brick chamber, and are imbedded in a mixture of new and spent tan. The pots are then covered with loose planks, and a second range of pots is placed upon the former, and also imbedded in tan, and in this way a stack is built up of eight or ten layers of pots to the height of 25 feet. At Newcastle-upon-Tyne, where white lead is extensively manufactured, a number of these stacks are arranged on each side of the enclosed space, each stack containing about 12,000 of the pots, and from 50 to 60 tons of lead. In France, pits of masonry are constructed for the purpose, and stable manure is the fermenting material. Fig. 1275 shows the form of pot employed, *l l* being a ledge for supporting the lead *c* which is bent into a coil *c′*. The acid is contained in *a*. The mouth of the pot is also covered over with strips or castings of lead, as shown in the figure, and then comes the plank *m n*, which serves, as it were, for the ceiling of one layer of pots, and the floor for another layer above it. Soon after the stack is completed the tan begins to heat or ferment, and the temperature of the interior rises to 140°, 150°, or higher. This causes the acetic acid slowly to volatilize, and the vapour passing readily through the gratings of the lead, acts as a sort of carrier between the carbonic acid evolved from the tan and the oxide of lead formed under the influence

Fig. 1275.



(1) "Manual of Metallurgy." 1852.

of the acid vapour and the oxygen of the air. The quantity of acetic acid used in proportion to the lead is so trifling, that it can only in an indirect manner lead to the production of the carbonate.[1] In the *first* place, an oxide is formed on the surface of the lead, and with this a portion of the acid vapour unites, to form a subacetate of lead. In the *third* place, the carbonic acid liberated by the fermenting tan decomposes the subacetate of lead, and converts it into a carbonate. *Fourthly*, the acetic acid thus set free determines the formation of another portion of sub-acetate, which becomes changed, in its turn, into carbonate. In this way the action proceeds, until, in the course of from four to six weeks, the fermentation of the tan is at an end. The stack is then unpacked, and the lead taken out; it retains the form in which it was cast, but has increased in size, and is converted into dense white carbonate. In some cases the conversion is complete; in others there is a central core of metallic lead; these variations depending upon the position of the lead in the stack, as also upon the season of the year, the temperature, and the state of the atmosphere. The factory is so arranged that the stacks are in different states of progress at the same time. The white castings of lead are passed through rollers, by which the carbonate is crushed and broken up, and the central core of *blue lead* thus separated from the *white*. The latter is next ground up into a thin paste, with water, and is then reduced, by successive washings and subsidences, to an impalpable powder. This is collected in earthen pans (each holding 10 or 12 lbs.), and arranged on iron shelves, in a room heated to about 190°. When dry, it forms an impalpable white powder, without any signs of crystalline structure, even when viewed under the microscope. In this beautiful and remarkable process the texture and purity of the metallic lead are points of importance. Rolled or sheet lead will not answer: the gratings, coils, stars, &c. must be of *cast* lead. The metal must also be pure; for if it contain iron, the white lead will be of a tawny hue, and if a trace of silver be present, it becomes dingy under the action of light.

If the white lead produced by the above process be intended for the use of the painter, it is mixed in a vat, with linseed oil, to the consistence of a very stiff paste, a mechanical stirrer being employed for the purpose; it is then ground between millstones, and is, lastly, packed into casks for the market. 1 cwt. of white lead requires about 8 lbs. of oil.

Other processes are adopted for the manufacture of white lead, which, however much they may differ from the Dutch method, and from each other, are very similar in principle, viz. the precipitation of a soluble salt of lead by means of an alkaline carbonate, or by carbonic acid; as for example: when a solution of nitrate or acetate of lead is decomposed by carbonate of soda, a dense white precipitate is obtained, which being washed and dried, is a pure white. It is found, however, by the microscope to consist of minute crystalline grains, a circumstance which interferes so much with the *body* or opacity of this white lead as to render it comparatively useless as an oil paint, no grinding or mechanical comminution being able to get rid of the crystalline character. The compound thus formed varies in texture according as the carbonate of soda is added to the nitrate of lead, or as the nitrate to the carbonate, the latter mode of precipitation furnishing a more impalpable powder than the former; but the solutions require care in the method of diluting. 2. The celebrated *Clichy white* (made at Clichy, near Paris) is prepared as follows:—A solution of litharge is made in acetic acid, in such a way as to obtain a basic acetate, containing a large quantity of oxide of lead. This is decomposed by carbonic acid obtained from the combustion of a mixture of coke and chalk; and the air which is propelled through the fire by means of a blowing machine is conveyed by pipes into the solution of subacetate of lead. The carbonic acid, which escapes abundantly from the earth in some localities, is used for a similar purpose. The oxide of lead is completely precipitated in the state of carbonate, and the liquor contains the whole of the acetic acid, which is used to dissolve a fresh quantity of oxide of lead, and the new solution is submitted a second time to the action of carbonic acid. Hence the same acetic acid may be used to transform an indefinite quantity of oxide of lead into ceruse; but as a certain portion of the acetic acid is dissipated in the course of the process, a small portion is added at each operation. The apparatus used in this process is shown in Section, Fig. 1276. V V is the vat in which is made the solution of litharge in acetic acid, *s* being a stirrer for assisting the operation. The solution is drawn off by a tap *c* into a second vat, or underback, V′, lined with copper: here the metallic lead, iron, copper, and a little chloride of silver, and other insoluble matters are deposited, and the clear liquor is decanted into a close vessel *j j*, through the cover of which pass about 800 tubes, dipping into the liquor, while their upper extremities are connected with a wide tube *p p* which is attached to the blowing apparatus *a k*: this is supplied with carbonic acid from the furnace F, which is charged with 1 measure of coke mixed with 2½ measures of chalk in small fragments. The carbonic acid escapes by the tube *t*. At the end of 12 or 14 hours, when the precipitation of the carbonate of lead is complete, the neutral acetate is drawn off into the underback *b′*, whence it is forced by a pump *e*, along a tube *m n*, back again into the vat V. The carbonate of lead is drawn off into the vat *b*, and the series of operations is then gone through as before. 3. In Button and Dyer's patent process carbonic acid is passed through a hot solution of subnitrate of lead, whereby carbonate of lead is precipitated, and the solution reverts to the state of neutral nitrate: this is converted again into subnitrate, by boiling with powdered litharge, and the

(1) Supposing 100 lbs. of real acetic acid to be present in the stack; this would contain about 47 or 48 lbs. of carbon, whereas 6,740 lbs. are required to furnish the carbonic acid required by the 50 tons of lead in the stack, in order to convert it into a carbonate.

precipitation is repeated continuously. The carbonic acid is obtained by the combustion of coke, and the gas is purified from sulphurous acid and sulphuretted hydrogen, by passing it through a washing apparatus, containing chalk and white lead diffused through water. The precipitated carbonate of lead is well washed, condensed into cakes, and dried in stoves. One of the great objections to this, in common with other precipitated white leads, is want of body; for while the white lead obtained by the Dutch process requires only 8 lbs. of oil per cwt., to bring it to the proper consistence for the painter, the precipitated white lead requires 16 lbs. of oil per cwt. 4. Under Torassa, Wood & Co.'s patent, granulated lead is agitated with water, by which a quantity of hydrated oxide of lead is formed, and this is subjected to the action of carbonic acid. This plan has not succeeded. 5. In Gossage and Benson's patent process, finely powdered litharge is moistened, mixed with about $\frac{1}{100}$th part of acetate of lead, and submitted, during constant stirring, to a current of heated carbonic acid: a subacetate of lead is successively formed and decom-

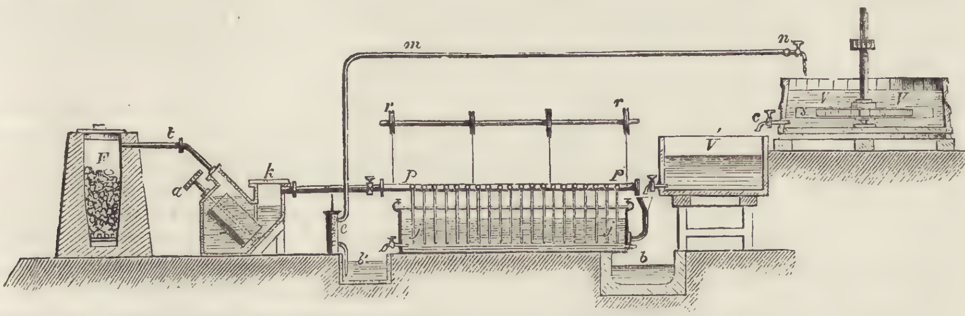


Fig. 1276. MANUFACTURE OF CLICHY WHITE.

posed, so that only a small quantity of the original acetate is required. 6. In Hemming's process, nitrate of soda is distilled with the proper quantity of sulphuric acid, by which nitric acid and sulphate of soda are formed: oxide of lead is dissolved in the nitric acid, and the sulphate is converted into carbonate of soda, in the usual way, by heating with coal and chalk; a solution of the carbonate of soda is then added to the solution of nitrate of lead, producing carbonate of lead and nitrate of soda: this nitrate of soda is then treated as before.

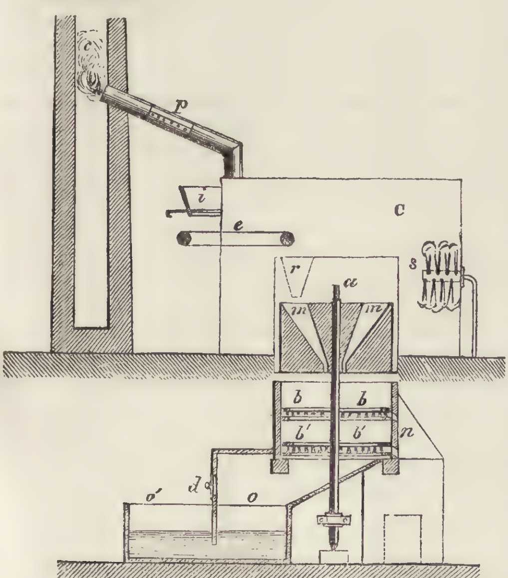


Fig. 1277. FRENCH METHOD OF GRINDING CERUSE.

The grinding and sifting of white lead are very injurious to the health of the workpeople unless care be taken to prevent the powder from flying about. A plan invented by MM. Hameline and Besançon for rendering these operations less dangerous is described by M. Payen in his excellent "Précis de Chimie Industrielle, 1851." The dried cakes of ceruse are put into a hopper *i*, through which they fall upon an endless band *e;* this conveys them into a mill, *m m*, which reduces the ceruse to powder. This powder falls upon a sieve *b b*, furnished with brushes, moving upon the same axis *a* as the mill: the larger particles, which cannot pass through the meshes, escape by side openings *n* into a close receiver: the powder which passes through the first sieve falls upon a second *b′ b′*, and thence down an inclined plane into a vessel *o o′*, which may contain oil if the ceruse is to be mixed therewith; or it may be collected in this vessel in the state of a dry impalpable powder. The chamber C, which surrounds the mills, has at its upper part a pipe *p* opening into a shaft *c*, the draught of which carries off the dust from C; but a large portion of the powdered ceruse is condensed in the chamber C by means of the jets of steam *s*, the condensation of which, precipitating the powder, prevents loss by way of the chimney.

White lead is largely adulterated with sulphate of baryta; a fraud which may be easily detected by digesting the sample in dilute nitric acid, which dissolves the carbonate of lead, but leaves the sulphate of baryta. *Venice white* is a mixture of equal parts white lead and sulphate of baryta; *Hamburg white*, one part white lead and two parts sulphate of baryta; *Dutch white*, one part white lead and three of the sulphate; *Krems* or *Kremnitz white*, *Silver white*, and the *Clichy white* already noticed, are pure white lead. A minute addition of indigo or of lamp black is sometimes added, to give a slight bluish shade to the white lead.

Section III.—Theory and Practice of Lead-smelting.

The native sulphuret of lead, or galena, is the chief source for supplying the commercial demand for lead in this country. The ore, having been picked, is broken and washed, for the purpose of separating earthy and siliceous matters; it is then roasted, at a moderate heat, so that about one-half of it shall be converted by the absorption of oxygen into sulphate of lead, the heat being so regulated as not to drive off any of the sulphuric acid. The sulphate thus formed having been well mixed up with the unaltered portion of the ore, the temperature is very rapidly increased, so that the two shall be fluxed together; the result of which is the conversion of the mixture into sulphurous acid gas, which passes off to waste, and pure metallic lead which is left behind. In this process the sulphur of the unaltered ore combines with the sulphur and oxygen of the portion which has been oxidized.[1]

The furnace in which these operations are carried on is represented in vertical section and ground plan, Figs. 1278, 1279. The sole is usually about 8 feet long

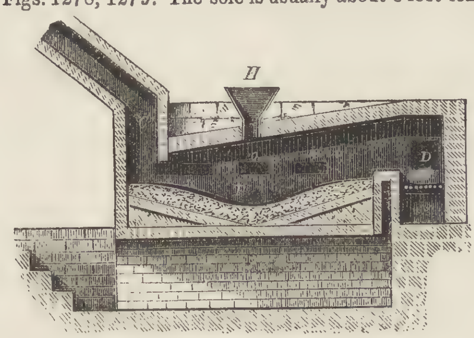


Fig. 1278.

and 6 feet wide, and is formed of the fused slags of previous operations, worked to the proper form while in a state of semi-fusion. About the centre of the hearth is a depression for the fused metal to collect in, and about this point is the tap-hole T, for drawing off the metal into the cast-iron pan P, set in a niche a little under the furnace side: F is the fire-place, B the bridge, and C the chimney, which communicates

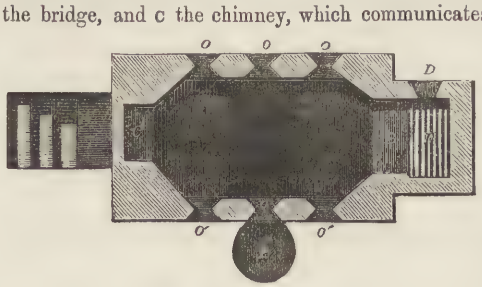


Fig. 1279.

with flues leading into condensing chambers. The arch of the furnace is about 14 inches above the top of the fire-bridge, and at the other extremity of the hearth descends to within 6 inches of it, by which means the flame is brought into close contact with the charge. In the centre of the arch is an iron hopper H, for letting in the charge. The door D, for supplying coals, is on what is called the "labourer's side" of the furnace; on the same side are three holes, *o o*, covered with iron plates, which are removed when the charge requires stirring or a supply of air. The opposite, or "working side" of the furnace, has also three small doors *o′ o′*, for working the charge or letting in air. The slag composing the sole is heaped up nearly to the small door on the labourer's side, and declines to the other wall, so as to communicate with the tap-hole.

The lead of one charge being drawn off, and the slags cleared out, the trap or damper of the hopper is withdrawn, and the whole of the charge let into the furnace. In the North of England the weight of a charge is about 12 cwt., and in Wales from 20 to 24 cwt. A labourer immediately spreads out the charge with an iron rake; the doors and dampers communicating with the flues are closed, but not sufficiently so to prevent the entrance of air. Every now and then the charge is stirred with an iron paddle, so as to expose fresh surfaces to the air, and during the first two hours very little fuel is added, the furnace retaining sufficient heat from the previous charge; but after this time some rich slags skimmed from the surface of the lead in the lead pan are thrown in through the doors furthest from the fire; the roasted oar is also turned over, with a long iron paddle. The rich slag soon gives up its metallic lead, and this is run out through the tap-hole. The charge is worked over with an iron paddle; the damper is raised a little; and as the temperature rises the fusing matters are brought back by the smelter to that part of the sole which is near the fire-bridge; and his assistant, who always works through the back doors, spreads them over the surface with his paddle. Some quicklime is thrown through the central opening upon the metallic lead, which begins to collect on the depressed part of the sole. After a short time the labourer again mixes up the charge, while the smelter pushes the slags back to the fire-bridge; the doors are then left open, and the slags begin again to flow back to the lower part of the sole. At the end of 3 or 3½ hours the damper is opened to the full; fresh fuel is added; all the doors are closed, and the furnace is left for ¾ hour. The doors are then opened; the assistant stirs up the charge, to assist the flow of metallic lead into the depression, and the smelter pushes back the slags. More quicklime is added in order to liberate a portion of oxide of lead, and also to make the slags less liquid and more easy of removal. As the oxide is set free it reacts on any undecomposed sulphuret which escaped decomposition in the roasting. More fuel is added to the grate, and a portion of powdered coal thrown into the furnace, to assist in the reduction of the oxide; the doors are again closed for 40 minutes, at the expiration of which they are opened, and the metallic lead allowed to flow out through the tap-hole.

(1) The whole process has been thus clearly represented by Fownes:—

Sulphate of lead	Oxide of lead	Lead	Free.
		Oxygen	2 Sulphurous acid.
	Sulphuric acid	Sulphur ...	
		3 Oxygen ..	
Sulphuret of lead		Sulphur ...	
		Lead.........	Free.

Some quicklime is added, in order to dry up the slags, which are removed by the labourer.

Mr. Phillips states that at Holywell each ton of ore smelted consumes 10 cwt. of coal; but at Grassington in Yorkshire, where a more fusible galena is employed, and more time allowed for the operation, $7\frac{1}{2}$ cwt. of fuel are required per ton. The whole *shift* of a furnace, including the time for casting the lead into pigs, occupies from $5\frac{1}{2}$ to 7 hours. During this time the frequent cooling of the furnace brings back the fused materials to a pasty condition, which allows of their being disintegrated by the action of the paddle, and exposes a larger surface to the air of the furnace; while the porosity of the mass allows streamlets of metallic lead to trickle down to the internal reservoir of the sole. The iron tools used in stirring up the charge are rapidly attacked by the fused galena.

The lead thus obtained contains a sufficient percentage of silver to render its separation profitable. Some ores, especially those of Spanish origin, contain also antimony, tin, copper, and other impurities, which must be separated before the lead can be treated for the sake of its silver. For this purpose the lead is fused in a furnace and exposed for many hours, and in some cases for 3 or 4 weeks, to oxidizing influences, by which means the antimony, tin, and other metals, as also a portion of the lead, become oxidized, and are gradually removed from the surface by an iron rake, so as frequently to expose a fresh surface to the action of the gases of the furnace, until most of the impurity is removed, and a nearly pure alloy of lead and silver is obtained. The silver was formerly separated from the lead by the process of *cupellation*, similar in principle, but on a much larger scale, to that explained under ASSAYING; but of late years Pattinson's process has been in the first instance adopted, as explained in our INTRODUCTORY ESSAY, p. xcix. By this process the original lead, containing about 10 ounces to the ton, is concentrated to about 300 ounces to the ton, while the desilvered lead does not contain more than 10 dwts. of silver to the ton. The silver is then extracted from the rich lead in a cupel-furnace called a *refinery*. Pattinson's process is so simple and economical in its action that the produce of silver in the United Kingdom has been more than doubled within the last 20 years. Large quantities of lead are also brought to England for the purpose of being desilvered by this process, which is now followed in most of the lead-mining districts of this country.

Fig. 1280, is a plan of the refinery in which the lead is separated from the silver. F is the fire-place, B the fire-bridge; the flame and heated air pass directly over the surface of the cupel C, and thence escape through the two openings *o o* into the flue *f*, which is connected with the main chimney. There is a small hood and chimney shown at *h*, for carrying off the injurious fumes of lead generated during the operation. The cupel or *test* is an oval iron frame, of which the greater diameter is 4 feet, and the lesser $2\frac{1}{2}$ feet: it is surrounded by a ring 4 inches deep, and strengthened by cross bars. It is filled with finely powdered bone-ash, slightly moistened with a weak solution of pearlash, which helps to give consistency to the bone-ash when heated. The bone-ash is well beaten down with iron rammers, and when the ring has been well filled the centre is scooped out with a small trowel, leaving a raised border of bone-ash all round as shown in the figure: at the fore part or *breast*, the width of

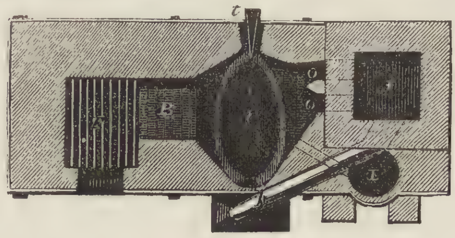


Fig. 1280.

this border is 5 inches, and at this point a hole is cut for the escape of the fluid litharge, for it is not in this large operation absorbed by the substance of the cupel, as in the delicate and exact operation of assaying. When the test is properly prepared it is lifted into the refinery, and wedged to its proper height against a fixed iron ring or *compass-bar*. The heat is applied with great caution, to prevent the test from splitting, and as soon as it is perfectly dry it is raised to a cherry-red heat, and filled through a spout with the rich lead previously fused in the cast-iron pot I, which has a small fire beneath it. The lead soon becomes covered with a greyish dross, but on increasing the heat, a covering of litharge begins to form. The blowing apparatus is now set in motion, and the blast from the tuyere *t* drives the litharge from the back of the cupel up to the breast, and over the gateway, when it falls through the hole in the cupel into an iron pot below. The blast not only sweeps off the litharge from the surface of the lead, but supplies the oxygen required for its formation. As the lead wastes away by the removal of the litharge, more metal is added from the melting up, and the process is continued until about 5 tons of rich lead have been poured into the test. When this has taken place the whole of the silver is left in the cupel in combination with only 2 or 3 cwt. of lead. This is now drawn off and another charge introduced, and when a sufficient weight of this rich lead has been collected to yield a cake of silver of from 3,000 to 5,000 ounces, the lead is again melted down, placed in a cupel, and the pure silver extracted. The test used for this purpose is so hollowed out as to produce a thick plate of silver, and allow space for the removal of the slags around its edges at the completion of the operation. When the last traces of the combined lead separate, the silver *lightens* as in the small cupel,[1] and very beautiful

(1) This phenemenon, as displayed in the small cupel, is very well described by Aikin, and is quoted in ASSAYING. The French chemists call it *l'éclair*. Regnault admirably describes it on the large scale in the third volume of his *Cours de Chimie*. He says:—"The moment when the oxidation of the lead ceases, and when consequently the cupellation is finished, is marked by a peculiar appearance called the *lightening*. During the whole period of oxidation the metallic bath appears more brilliant than the walls of the furnace. Its temperature is, in fact, higher; for not only does it share in the heat of the furnace, but its temperature is

arborescent forms are produced on the surface of the plate. When very rich lead is operated on, the plate of silver may be worked off at once from the refinery. The litharge produced during the operation, as also the cupel bottoms, contain silver, and these are operated on for the recovery of that metal.

By the improved methods of enriching and refining, lead containing only 3 ounces of silver to the ton may be advantageously treated for its silver: whereas formerly, from 9 to 11 oz. of silver per ton. were required to make the operation profitable, and then the whole of the associated lead had to be converted into litharge, and this had to be again reduced at great expense of labour and fuel, in order to recover the metallic lead. If tin or antimony were present in the argentiferous galena, the difficulties were of course increased.

The litharge from the refinery, the pot dross and the mixed metallic oxides from the calcining pans, are treated for the recovery of the metallic lead, in a reverberatory furnace similar in form but smaller in dimensions to the smelting furnace; the sole is also differently arranged, for it is made to slope gradually from the fire-bridge to the flue, where there is a depression and a tap hole, which is left constantly open for the lead as it is reduced to flow out into an iron basin placed for the purpose, and from which it is laded into moulds, which bear the name of the smelting company by which it has been prepared. The litharge is mixed with small coal, and the sole is also covered with a layer of bituminous coal, which with the aid of the reducing gases effect the reduction of the litharge. A furnace of this kind, with a sole 6 feet by 5, will from ordinary litharge afford about 3½ tons of lead in 24 hours.

THE SCOTCH FURNACE. In Durham, Cumberland and Northumberland, the ores of lead are smelted in what is called a *Scotch furnace* or *ore-hearth*. It is of very simple construction, consisting of a rectangular cavity of masonry C, Figs. 1281, 1282, lined with cast-iron. The sole-plate *s* is also of cast-iron, and has an upright ledge at its back and two sides. In front of the hearth is another cast-iron plate *w*, called the *work-stone*, also surrounded with a ledge except towards the sole, but it often happens that the sole-plate and the work-stone are formed of one casting. The plate has a slope from behind forwards, and its hinder ledge is about 4½ inches above the surface of the hearth, and in some cases is separated therefrom by a cavity into which is rammed a wet mixture of powdered bone-ash and galena; the melted lead cannot penetrate this, but after filling the basin formed by the raised ledge at the bottom of the furnace, flows out by the gutters *g* in the work-stone, and is received into a melting pot P, placed below the front edge of the work-stone. The hinder ledge of the sole is surmounted by a piece of cast-iron, called the *back-stone*, on which the tuyere *t*, is placed. This supports another piece of cast-iron called the *pipe-stone*, scooped out in its under part for the passage of the tuyere. This piece advances 2 inches into the furnace, the back wall of which is crowned by another piece of cast-iron, also called the *back-stone*. On the ledges of the two sides of the sole are two *bearers* of cast-iron advancing an inch or two above the hinder edge of the work-stone; above these, at the height of 5 inches, and 12 inches from the back of the hearth, is another bar of cast-iron, resting on fire bricks, called the *fore-stone*. The space at each end of the fore-stone is closed by a cube of cast-iron, measuring 6 inches on the side, called a *key-stone:* two others are also used for filling up the space between the fore-stone and the back part of the furnace. The front of the furnace is open for about 12 inches from the lower part of the front cross-piece or fore-stone up to the upper part of the work-stone, and through this opening the smelter operates. The escape of fumes into the smelting house is prevented by enclosing the entire hearth in a hood of arched masonry or brickwork, which is bound together by heavy iron straps, passing beneath the foundation of the hearth, and kept in place by screw-bolts.

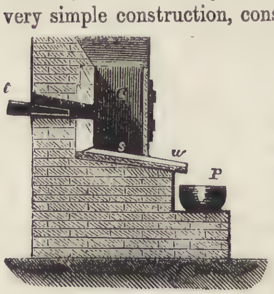


Fig. 1281.

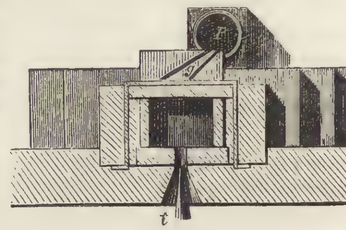


Fig. 1282.

Before the galena or other ore is smelted in this furnace, it is first roasted on a long flat hearth covered by a low arch, and heated by a fire-place at one end. From 9 to 11 cwt. of ore form a charge, and from 2½ to 3 hours are required for the roasting. The temperature is kept below the melting point of galena, and the object of the operation is partially to oxidize and to get rid of sulphur. Copious fumes of sulphurous acid escape from the surface, thus getting rid of a portion of the sulphur, antimony, &c., and should any portion approach the fusing point and become clammy, a fresh surface is exposed to the air. In this way the slime ores and other friable matters are so far agglutinated as not to be liable to be carried off by the blast in the smelting furnace.

After each shift in the smelting furnace, there is left on the hearth a portion of ore which has been only partially reduced. This is called *browse:* it is

also raised by the heat which is disengaged by the chemical combination of the lead with the oxygen. When, however, the lead is completely oxidized, this second source of heat no longer exists; the disk of metallic silver quickly sinks down to the temperature of the furnace, and instead of being brilliant as it was before, it becomes dull. On the other hand, at the moment when the last traces of lead oxidize, there is on the surface of the metallic bath only a pellicle of fused litharge; this quickly becomes thinner and thinner, and presents in rapid succession the colours of thin plates or of the soap-bubble, then becomes torn up like a veil, and discloses the surface of the metal. It is this rapid succession of optical phenomena to which the name of *l'éclair* or the *lightening* is applied."

mixed with fragments of coke and clinkers, and is used in the next charge. At every new shift the cavity of the furnace is filled up with rectangular blocks of peat built up in a wall towards the front. An ignited peat thrown before the tuyere *t*, the blast being on, soon ignites the whole. A little coal is next thrown on, and then a quantity of the browse. After this most of the matters contained in the furnace are drawn over on the work-stone by means of a large rake: the refuse of the ore, called *grey-slag*, which has a more shining appearance than the browse, is taken off with a shovel, and thrown outside the furnace to the right. The browse left on the work-stone is now thrown into the furnace with the addition of a little coal. A peat is put before the nozzle of the blast to prevent it from becoming stopped up, and also to divide and diffuse the blast. If the browse be not well cleansed from the slag, which is known by its soft state and tendency to fuse, a little quick lime is thrown in, which *dries up* the materials, and allows the earthy parts to form into lumps or balls; so also if the ore be refractory from the presence of silica, alumina or iron, lime is added to make them more fusible. The lumps of grey-slag contain from $\frac{1}{10}$th to $\frac{1}{15}$th of the lead which was present in the ore: these are afterwards smelted in the slag hearth at a higher temperature. When the browse has been thrown back into the furnace, a little of the ore is strewed over it. After 10 or 15 minutes the materials in the furnace are again drawn upon the work-stone, the grey-slag is removed by the rake, and a portion of metallic lead is carried off by the channels into the pan. Another peat is then placed before the tuyere, coal and quicklime are introduced in suitable proportions; the browse is thrown back into the furnace with a fresh portion of ore upon it, and another interval of 10 or 15 minutes is allowed, when the slag is again separated and another portion of metallic lead escapes into the pan. This method of working is continued for 14 or 15 hours, forming a *smelting shift*, during which from 20 to 40 cwt. of lead, and even more, are produced. This lead is much purer than that produced by the smelting furnace, because, on account of the comparatively low temperature employed, the lead and the silver only are sweated out, the other metals not being reduced.

The slags which are sufficiently rich to go through a distinct process for the recovery of the lead are treated in a slag furnace, the construction of which is very much like that represented in our Introductory Essay, Figs. LI., LII., LIII., and corresponding with the *fourneau à manche* (elbow-furnace) of the French, and the *krummofen* (crooked furnace) of the Germans. This furnace has the form of a rectangular prism, 26 inches in length, 22 in breadth, and 33 in height. The bottom is composed of a cast-iron plate, slightly inclining from the side of the tuyere towards the front of the furnace. On each side of the bottom plate are bearers, as in the ore-hearth, supporting the fire-hearth, which consists of 2 stout plates of cast-iron, about 12 inches broad and 26 long. A space of about 5 inches is thus left between these front *stones* and the bottom of the furnace, and an extra height of $2\frac{1}{2}$ inches is gained by placing between them a row of fire-bricks. The slags which escape through the opening at the breast pass over the surface of a pot, and are then received into a large iron cistern sunk in the earth, through which cold water is constantly flowing. This makes the liquid slags fly to pieces, and adapts them to the subsequent operation of washing.

In working this furnace the bottom is covered to the height of 15 inches with small spongy cinders beaten closely together: the pot for the reception of the lead is also filled with them. The rectangular space is then filled with peats and ignited under the influence of the blast: a layer of coke is next thrown on, and when the temperature is high enough a layer of grey slag or other scoriæ is introduced. Alternate layers of coke and slag are thrown in from time to time, and the slag and the lead being made perfectly fluid, the metal filters through the bed of peat-cinders, while the slag being by its viscidity retained above them, the lead is thus separated. When the coke bed becomes covered with fluid slag, the workman perforates it with a bent iron rod, and the liquid silicates run off by this orifice, and after passing over the surface of the pot for the reception of the lead are received into the water cistern.

The lead obtained by this process is, on account of the high temperature employed, of inferior quality; it is therefore not adopted for ores which admit of being economically worked at the smelting furnace or at the ore-hearth. The slag-hearth is, however, used for those ores which yield only a small per-centage of metal, and also for some of the foreign carbonates, in which the object is rather to extract the silver than economise the lead.

In all smelting establishments there is some difficulty in preventing a considerable portion of lead from being carried off in the form of *fume*, in consequence of the ease with which lead sublimes at a high temperature. This not only occasions loss to the smelter both in lead and silver, but is also very injurious to the vegetation and cattle of the surrounding district. In order to prevent the dispersion of the lead fume, the flues of the various furnaces are at some works contrived so as to communicate with large chambers in which cold water is made to shower down from the roof. The gases from the flues are also in some places drawn through cold water in order to separate ingredients which are of value if preserved, but highly noxious if dispersed through the air in their elastic form. Unfortunately, the arrangements required for working these contrivances are costly and not always successful. A model of the condensing apparatus used at the Duke of Buccleuch's works, at Wanlock Lead-hills, in Dumfriesshire, was exhibited in the Great Exhibition. An oblong building in solid masonry about 30 feet in height is divided by a partition wall into two chambers; adjoining these and communicating with one of them at the bottom is a tall chimney or tower. The smoke from the various furnaces, of which there are 8, situated

about 100 yards from the condenser, is carried by separate flues into a large chamber; from thence by a larger chamber it enters the bottom of the first chamber of the condenser, and is forced upwards in a zigzag course towards the top, passing 4 times through a shower of water which is constantly falling from a pierced reservoir at the summit of the tower. The smoke then passes through a cubic space filled with coke, through which a stream of water filters downwards. The smoke having reached the top passes into an *exhausting chamber*, which is about 5 feet by 7, and upwards of 30 feet high. Above this is a large reservoir well supplied with water; it has an iron bottom, in which are 12 slots or openings about an inch wide, extending across the reservoir, and communicating directly with the chamber beneath. On this iron plate works a hydraulic slide plate, with openings corresponding in one position with those in the reservoir. This plate receives a horizontal reciprocating motion from a water-wheel or other power driven by a connecting-rod and crank. In the middle of every stroke the openings in the plate correspond with those in the bottom of the reservoir, and a heavy shower falls through the vacuum chamber sweeping the enclosed space, and carrying with it the matters suspended in the vapours of the furnaces. The water saturated with particles of lead, &c., held in mechanical solution, is passed into large dykes or reservoirs, where it deposits its metal. The specimens of fume exhibited, were said to contain about 33 per cent. of pure lead, and about 4 oz. 17 dwts. and 7 grains of silver to the ton.

The satisfactory results of the above arrangement are stated at page c. of our Introductory Essay. In some other districts the condensing apparatus does not perform its work satisfactorily, or there is even no attempt made at condensation. In a paper by Dr. George Wilson, read to the Royal Society of Edinburgh, and contained in the Monthly Journal of Medical Science for May 1852, the writer states that within the short space of five months in 1851, he had to make a series of analyses in connexion with the death of 13 horses, which together with several cows, were supposed to have been poisoned by compounds of lead transferred by the atmosphere or by water to the fields in which they were pastured. The herbage of these fields was found to be impregnated with carbonate of lead, and in two of the cases, the water which the animals drank proceeded from the mine and was employed in washing the ore: this also contained carbonate of lead. On analysis, lead was found in several organs of the body, especially in the spleen, and Dr. Wilson remarks, that this is probably the most convenient organ for analysis. "Its small size, its loose spongy texture, and its comparative freedom from fatty matter, enable it to be rapidly and satisfactorily examined. In many cases, if lead were found in the spleen, it would not be necessary to seek for it elsewhere."

In the German method of smelting the fume is condensed by making the smoke pass through a series of chambers before it escapes into the air. The general arrangements of the smelting hearth in Germany and some other parts of Europe are different from those adopted in this country. With poor ores and a siliceous gangue the method applied to moderately rich galenas would entail the loss of a great deal of lead in the form of oxide, which would not react upon the undecomposed sulphuret, but would combine with the silica to form a vitreous slag very difficult to reduce. Metallic iron is, therefore, employed to reduce the sulphurets of lead: the iron combines with the sulphur of the lead, forming a fusible sulphuret of iron, and the lead is set free. For an account of the processes connected with this operation, we must refer to Regnault's "Cours de Chimie," tome 3me, or to Phillips's Manual of Metallurgy.

Section V.—Manufactures in Lead.

The chief applications of metallic lead in the arts are in the form of sheets for covering roofs and pipes for conveying water. It is also used in certain alloys, such as *type-metal*, *solder*, &c. [see Alloy,] and also in the manufacture of *shot*.

Sheet-lead.—The manufacture of sheet-lead by the old method, is conducted much in the same way as plate-glass is cast, only more roughly. [See Glass.] A stout table or bench 15 or 20 feet long, and 5 feet wide, with a raised margin, is covered with fine river sand. The melted lead is ladled into an oblong trough, suspended over the table, and this is then upset upon the sand. Two men then place a wooden strike, Fig. 1283, across the table, and resting the parts *b b* upon the raised edges, pass it quickly along by the

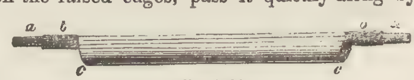


Fig. 1283.

handles *a a*, thereby spreading out and driving forward the molten metal, by means of the edge *c c*, leaving behind them a plate of tolerably uniform thickness, to cool upon the sand, the overplus of lead flowing off at the foot of the table into a box. Lead produced in this way is considered to be less liable to contraction and expansion, and consequent fracture from change of temperature, than sheet-lead prepared by *milling* or *rolling*. This is prepared in the following manner:—the metal is first cast in an iron frame, into a plate from 6 to 7 feet square, and 6 inches thick. It is lifted by a crane upon the *rolling-mill*, which is a long frame or bench, 8 feet wide, and from 70 to 80 feet long. At intervals of a foot, and on the same level are wooden rollers *r r*, Fig. 1824, to allow of the easy motion of the heavy sheet of lead L. The laminating apparatus is in the centre of the frame. It consists of two heavy cylinders, the upper of which, C, is seen in the figure. These cylinders are each 16 inches in diameter: they are turned as truly as possible, and the distance between them is regulated by means of the screws *s*, by turning the disc *d*, which is furnished with a graduated plate and pointer. There is also an arrangement for reversing the motion of the rollers.

The plate of lead, cast as before described, is

passed between the rollers, by which it is strongly compressed and elongated; the distance between the

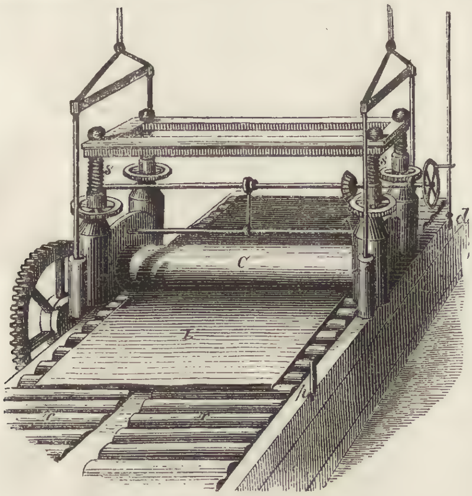


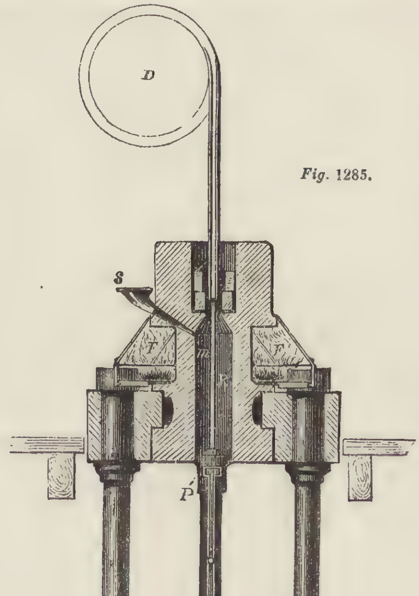
Fig. 1284. ROLLING MILL.

rollers is then diminished, the motion of the mill is reversed, and the sheet is again passed through. When the lead escapes from the grip of the rollers, it is again passed between them by two men standing one on each side of the frame, and with a crow-bar pressed against the edge of the lead, and the pins *p* as a fulcrum, the lead is again pressed into the grip of the rollers, the motion of which is reversed at each passage. This operation is repeated a number of times, passing backwards and forwards through the rollers until it is greatly diminished in thickness, and increased in length. When the length becomes too great to manage conveniently, the plate is cut into two parts, and each part is milled separately. The lead may have to pass 200 or 300 times between the rollers, whereby the original length of 6 or 7 feet may be increased to about 400, the breadth being 7 feet. This is cut up into shorter lengths, and made up into a roll for the use of the plumber, who designates sheet lead by terms indicative of the weight of a square foot as 5, $5\frac{1}{2}$, 6, $6\frac{1}{2}$, 7, $7\frac{1}{2}$, 8, $8\frac{1}{2}$ lbs.

Lead pipe.—This is formed by casting a short but very thick plug or cylinder of lead, with a bore in the centre of the exact size required. The plug is then put upon a long steel mandril of the size of the bore, and passed between rollers with grooves of different sizes, according to the external diameter required; or the plug may be drawn through metal *wortles* or collars of different sizes, each succeeding hole being less than the former, until the pipe is extended to the length and thickness required. By this method the lead is compressed and rendered more durable. A bright smooth surface is given to the pipe by passing it once or twice through a cutting die, which shaves off a thin film of the metal. The pipe is dragged through the holes in the collars by means of an endless chain, passing round two wheels or rollers set in motion by steam-power.

The only objection to this method is the limited length of the pipes so produced, 20 or 30 feet being the greatest. When a very long pipe without joints is required, the *hydrostatic pipe-press* is used. This consists of an ordinary hydrostatic press, situated below the floor of the workshop: above this is a cylindrical reservoir R, Fig. 1285, for the reception of the fluid metal: this is surrounded by an annular fire-place F, which is filled with live coals, and provided with a chimney for carrying off the smoke. At the upper extremity of R, a steel die is fixed, of the diameter required for the outside of the pipe: through the centre of this die passes a mandril of the size required for the bore. The reservoir R is filled with melted lead through the spout *s*, which is then removed and the aperture stopped with a stout iron plug. The hydrostatic press being then set in action, the piston P, attached to the top of the ram, is slowly driven upwards into the reservoir R, driving the melted lead before it. The lead in escaping is thus forced through the annular space between the mandril and the fixed collar, by which means a perfectly finished pipe is formed, and as it escapes it is coiled round the drum D. In this way pipes of very great lengths may be formed.

Fig. 1285.



LEATHER is a chemical combination of skin with the astringent vegetable principle called *tannin* or *tannic acid.* The manufacture in Great Britain ranks next in importance to that of cotton and of wool, and is probably equal to that of iron. There is a large and constant demand for leather as an article of clothing: it enters into the construction of various engines and machines; supplies harness to our horses, linings to our carriages, and covers to our books. For all the varied purposes to which leather is applied it is well adapted, and it was probably at the earliest period of man's history that an art so necessary to his comfort and welfare became known. The

skins of animals taken in the chase are in their fresh state tough, flexible, and elastic, and seem, at first view, to be well adapted for clothing; but in drying they shrink, become horny, pervious to water, and, on exposure to moisture, putrid and offensive. But if the skin be separated from fleshy and fatty matters, and then be put into a solution of certain vegetables containing tannin, which abound in almost every country, the skin separates the whole of the tannin from the liquid, and becomes hard, insoluble in water, almost impenetrable by it, and incapable of putrefaction. The subsequent operation of currying renders it pliable and more waterproof. Similar but less decided changes are produced upon the skin by impregnating it with alum, and also with oil or grease. The object of these processes being to render soft and flexible that which would otherwise be hard and unyielding, the skin thus transformed was called by our Saxon ancestors *lith, lithe*, or *lither*,—that is, soft, or yielding; whence our term, *leather*. The word *tan*, and the French *tanner*, are from the Low Latin, *tanare*.

Section I.—The Skins used in Preparing Leather.

The hide or skin of an animal consists of three distinct parts, viz.—the *epidermis* or *cuticle*, which is covered with hair or wool; below this is the *reticulated* or *net-like* tissue; and, thirdly, the *dermis, corium, cutis*, or true skin, which is in contact with the flesh. This last is the only part which can be tanned; so that it is necessary to get rid of the two former before the conversion into leather can be commenced. The true skin is a thick, dense, hard membrane, composed of fibres interlacing each other in a curious complex manner, and more thickly woven towards the surface than below it: it is not equally thick throughout, for those parts which cover the mane, the back, and the rump, are much thicker than the parts which cover the belly. The dermis is also pervaded by a large number of minute conical channels, the small extremities of which terminate at the exterior surface of the skin: these channels, which are placed obliquely, contain nerves, secretory vessels, and cellular membrane. A fresh skin, from which the fat and cellular tissue has been separated on the internal or flesh side, and the epidermis and mucous membrane from the external or hair side, contains about 43 per cent. of solid matter, the remainder being water. By digesting the true skin in boiling water, it becomes altered in its properties; it is nearly all dissolved, and, by slow evaporation, leaves a residue of *gelatine* or *glue*. It is stated by some chemists, that skin, membrane, &c. do not contain gelatine ready formed; that this substance does not exist in the animal kingdom, but that it is generated by the action of hot water upon certain animal substances. Whether this be the case or not, chemists are agreed in applying the term *gelatinous tissues* to all those animal tissues which produce gelatine by the action of boiling water. At the ordinary temperature, these tissues are converted into gelatine by the action of dilute acids and alkalis.

Notwithstanding the vast consumption of animal food in Great Britain, the skins of the slaughtered animals by no means suffice to supply the demands of the tanner. Large quantities of skins are imported from various parts of the world, a short notice of which may be of interest in this place.

All tanned leather is classed under the denominations of Hides, Kips, and Skins. From these there are various kinds of leather tanned in England: 1st. *Butts* and *backs:* these are selected from the stoutest and heaviest ox-hides. The butt is formed by cutting off the skin of the head for glue; also the cheeks, the shoulder, and a strip of the belly on each side. In the *back*, the cheeks and belly are cut off, but the shoulder is retained. 2d. *Hides* consist of cow-hides, or the lighter ox-hides; they are the same as *butts* with the bellies on. Hides are sometimes tanned whole, and are struck for sole leather, in which case they are called *crop-hides*. 3d. *Skins:* these are used for all the lighter kinds of leather.

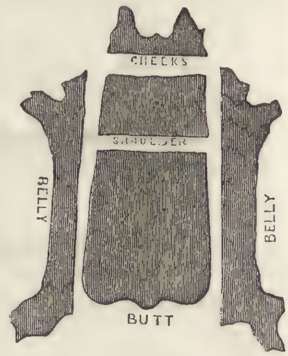


Fig. 1286.

The hides of South America are in high repute; they are the produce of the half-wild cattle which pasture on the wide plains between Buenos Ayres and the Andes. Hides are also imported from various parts of Europe, as also from Morocco, the Cape of Good Hope, and other places. They are imported *dry* or *salted*.[1]

The *butt* or *back* of the ox-hide forms the stoutest and heaviest leather, such as is used for the soles of boots and shoes, for most parts of harness and saddlery, for leather trunks and buckets, hose for fire-engines, pump-valves, soldiers' belts, and gloves for cavalry. Formerly, when the use of metallic armour was on the decline, its place was supplied by a very thick, pliant leather, made from the hide of the urus, or wild-bull of the forests of Poland, Hungary, and some parts of Russia. This animal was commonly called the *buffe*, whence originated the term *buff-leather*. The Russian Company chartered by Henry VIII. was compelled to import a certain number of buffe-hides, to be manufactured for military purposes. Real buff-leather was pistol-proof, and would turn the edge of a sword. During the wars of Charles I.'s reign, it was in great request, but it afterwards declined. The hides of the real buffalo of Italy were also imported for the same purpose. The modern buff-leather is made from cow-hide, and is used for little else than soldiers' belts.

(1) The following were the imports into the United Kingdom for the years 1850 and 1851:—

	River Plate & Rio Grande. *Dry.*	*Salted.*	*East India* *Kips.*	*Horse-Hides.*
1850	29,820	630,400	1,606,380	231,510
1851	62,640	749,540	2,262,700	140,640

Bull-hide is thicker, stronger, and coarser in its grain than cow-hide. The hide of the *bullock* is intermediate between the two. *Calves'-skin* is thinner than cows', but thicker than most other *skins.* It is tanned for the bookbinder; but the greater part of the supply is tanned and curried for the upper part of shoes and boots.

Sheep-skins are supplied chiefly by the home markets, but many thousands are imported from the Cape of Good Hope, and are considered to be superior to those of English growth: they are distinguished by the greater width of the skin that covers the tail. They are simply tanned, and employed for various purposes for which a thin, cheap leather is required; such as for common book-binding, leathering for common bellows, whip-lashes, bags, aprons, &c. Sheep-skins also form the cheaper kinds of wash-leather for breeches, gloves, and under-waistcoats; as also coloured and dyed leathers, and mock-morocco, used for women's shoes, for covering writing-tables, stools, chairs and sofas, lining carriages, &c.

Lamb-skins are chiefly of home produce; they are also imported from the north of Italy, Sicily, and Spain. They are dressed white or coloured for gloves.

The skins of *goats* and *kids* form the best kinds of light leather. The chief supply of the best kid-skins is from Switzerland and Tuscany, whence they are shipped, chiefly at Leghorn. *Goat-skins* are principally obtained from the coast of Barbary and the Cape of Good Hope. They form the best dyed morocco of all colours. Kid-skins supply the finest white and coloured leather for gloves and ladies' shoes.

Deer-skins are, to some extent, supplied by our parks; but the chief supply is from New York and New Orleans; a few are sent from Canada, and some from India. *Antelope-skins* from the Cape of Good Hope are of good quality. Deer-skins are all *shamoyed,* or dressed in oil, chiefly for riding-breeches. Shamoyed leather, of sheep, goat, and deer-skins, was formerly a lucrative branch of the leather trade of this country. This kind of leather was employed chiefly for breeches, white or dyed, worn by persons who rode much on horseback. The English shamoyed leather was so much esteemed, that it was not only worn by our own cavalry, but by that of Prussia, Austria, and most of the German states. During the Peninsular war, however, it was noticed by the British commander that in wet weather the leathern garments fitted close to the skin, and were long in drying, so that the men were liable to colds, rheumatism, and other complaints arising from this cause. Woollen cloth was therefore substituted, and the example being speedily followed by Austria and Prussia, this branch of the leather trade speedily declined.

Horse-hide is tanned and curried for harness work, for collars, &c. It has of late years been substituted for *seal-skin,* but does not produce so good a leather. Enamelled horse-hide, split or shaved thin, is used for ladies' shoes, in imitation of seal.

Dog-skin is thin, but tough, and makes good leather. The supply is limited to this country, but has fallen off of late years; horse-leather taking its place for thin dress-shoes. But most of the *dog-skin gloves,* as they are called, are really made of lamb-skin. *Seal-skin* makes a valuable leather, but a large proportion of the supply of seal-skins is used as fur for covering caps.

Hog-skin affords a thin, porous leather, which is used for covering the seats of saddles. The common custom of cooking pork with the skin on greatly limits the supply, which is chiefly from Scotland and Yorkshire.[1]

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(1) The following selection from the "Prices Current," contained in the circular of Messrs. W. T. Goad & Rigg, of Mark Lane, forms a good illustration of the extent and variety of the trade in hides and skins:—

OX AND COW-HIDES.

	Weight.		Prices Duty free. *d.*
Buenos Ayres and Monte Video:—			
Dry—			
Best heavy	29—32 lbs.	at per lb.	6½—
Common ditto	30—34	,,	4½—5½
Best light	21—24	,,	5¾—6
Bulls	38—42	,,	4 —4½
Salted—Heavy ox			3½—4
Rio Grande and Rio Janeiro:—			
Dry—			
Best heavy	32—34	,,	5 —5½
2d sort	20—30	,,	4½—5
Salted—Cow			3 —3¼
Valparaiso, Lima, Punta, Arenas, &c.:—			
Dry—1st sort	24—30	,,	5¼—5½
Brazil:—			
Dry Salted			3¾—4
Wet Salted			2¾—3¼
Cape:—			
Dry			4 —5
Salted heavy			3 —3⅝
Kips and Skins			4 —5½
New South Wales:—			
Salted			2½—2¾
North American:—			
Salted			2½—2¾
West India:—			
Dry			2½—4½
East India:—			
Dry Salted			3 —8¼
Brined			3½ - 7½
Buffaloes			2½—4¼

HORSE-HIDES.

Buenos Ayres:—		
Salted	per hide	4*s.*—6*s.*
Rio Grande	,,	4*s.* – 5*s.*
German—dry	,,	4*s.*—5*s.*
Russian	,,	4*s.*—5*s.*

KIPS—DRY.

		d.
Buenos Ayres	per lb.	7 —7½
African	,,	3 —6
Petersburg, 8— 9 lbs.	,,	8¾—9
,, 10—12 ,,	,,	8½—8¾
Cape	,,	4½—6
Mogadore	,,	3½—5½

SKINS.

		s.	*d.*	*s.*	*a.*
Nutria	per doz.	10	0—	15	0
Chinchilla	,,	7	0—	52	0
Deer, Buenos Ayres large red	per skin	1	0—	2	0
small thin	,,	0	6—	0	9
Vicuna, Buenos Ayres & W. Coast	,,	2	6—	3	0
Sheep—Mogadore	per doz.	15	0—	22	0
Buenos Ayres	,,	10	0—	18	0
Trieste	,,	10	0—	15	0
Tuscan	,,	16	0—	18	0
Cape	,,	12	0—	28	0

Section II.—Vegetable Substances used in Tanning.

The tannin or tannic acid of different vegetables does not appear to be the same astringent substance. The differences between tannins from different sources are small, and are chiefly interesting to the chemist. There are, however, certain broad features which are alike in all. Tannin is characterised by an astringent taste, and by its bluish-black or dark-green precipitates from aqueous solutions, by the solution of salts of the peroxide of iron: it also affords a dirty-white or brown precipitate with a solution of gelatine. A solution of protosulphate of iron does not precipitate a solution of tannin, until, by exposure to the air, oxygen is absorbed, and a peroxide of iron is formed. This change, however, is very rapid. If cold aqueous solutions of tannin and animal gelatine (such as glue, size, or isinglass) be mixed in certain proportions, both are thrown down as a precipitate, which is called *tanno-gelatin:* it contains about half its weight of tannin. If heat be applied, or the acid be in excess, the precipitate forms, on stirring, a viscid, elastic mass, resembling caoutchouc.

Tannin is most easily procured in its pure state from gall-nuts. These must be coarsely powdered, and placed in a glass percolator, Fig. 1287, the bottom of which is plugged with cotton. Ether containing a small quantity of water is then poured in, and after several hours, when the liquor has filtered through, more ether is added. The liquor collected in the lower vessel separates into two layers, the lower of which is of an amber colour, and consists of a solution of tannin in water. The upper solution contains gallic acid and some other matters. The aqueous solution, on being gently evaporated, leaves a shining, porous, uncrystallizable mass of tannin, nearly pure. In this way from 35 to 40 per cent. of tannin may be obtained from galls. It may be preserved in close vessels without change. Tannin is soluble in water, and the solution has the properties of a free acid. Exposed to air, it absorbs oxygen, disengages an equal volume of carbonic acid; the tannin disappears, and two new products, viz. *gallic acid* and *ellagic acid,* are formed. The former is soluble, the latter an insoluble powder, of a yellow-grey colour. Tannin is precipitated from its solutions by sulphuric, muriatic, phosphoric, boracic, and arsenic acids. If the compound with sulphuric acid be boiled for a few minutes in dilute sulphuric acid, gallic acid is formed, which is deposited in crystals on cooling.

Fig. 1287.

Gallic acid exists ready formed in gall-nuts, sumach, mango-seeds, divi, valonia, tea, &c. and is probably formed in all cases from the decomposition of tannin. It is not so soluble in cold water as tannin, but is very soluble in hot. It does not combine with gelatine or gelatinous tissues as tannin does, and hence is little or no use to the tanner. The tannin of gall-nuts and sumach is more liable to pass into gallic acid than any other description of tannin. This change in the case of gall-nuts, and probably, also, in other cases, is expedited by the contact of the insoluble vegetable matters which remain after the tannin is extracted. Pyroligneous acid retards the decomposition of tannin, while tartaric, malic, and vegetable acids in general, accelerate it. Sumach is peculiarly liable to fermentation, probably in consequence of the malic acid present in the leaves. Hence it is of great importance to the tanner to become acquainted with the circumstances which favour the conversion of tannin into gallic acid, and to avoid them if possible, for this is a positive source of loss. In the spent or waste tan liquors there is a considerable proportion of gallic acid. There is an opinion among tanners, that the presence of gallic acid is useful; and when hides have been cleansed with lime-water, they are left for a time in the waste liquor, the gallic acid of which is said to expand the hides, and facilitate the penetration of the solution of tan, when the hide is transferred to a stronger liquor. Now, as almost any other acid would answer this purpose (indeed water soured with sulphuric acid is so

		£ s. d.	£ s. d.
Italian Kid	per 120	6 0 0	8 10 0
Lamb	,,	4 10 0	6 5 0
Ancona Kid	,,	7 0 0	8 10 0
Lamb	,,	5 0 0	6 15 0
Tuscan Kid	,,	8 0 0	10 10 0
Lamb	,,	5 10 0	9 10 0
Naples Kid	,,	4 10 0	6 10 0
Lamb	,,	4 10 0	5 10 0
Sicily Kid	,,	5 0 0	7 0 0
Lamb	,,	3 0 0	4 10 0
Trieste Kid	,,	5 0 0	6 5 0
Lamb	,,	4 10 0	6 10 0
Bilboa Kid	,,	7 0 0	8 10 0
Lamb	,,	4 10 0	7 0 0
Spanish Lamb	,,	5 15 0	8 0 0
East India Kid	per doz.	0 5 0	0 7 0
Buenos Ayres Lamb	,,	0 6 0	0 12 0
Goat, Lisbon	,,	0 6 0	0 18 0
Cape	,,	0 15 0	2 9 0
Mogadore	,,	0 12 0	0 18 0
Seal-Fur—Large wigs	per skin	0 5 0	1 12 0
Middlings and smalls	,,	0 12 0	1 15 0
Large pups	,,	0 11 0	1 8 0
Newfoundland	,,	0 2 6	0 6 0
Greenland	,,	0 1 1	0 5 6
Horsehair.		s. d.	s. d.
Long Combed, Buenos Ayres, clean	per lb.	1 9	2 3
Tails rough, Buenos Ayres	,,	0 10	2 0
Good mixed	,,	0 9½	0 10½
Fair mixed	,,	0 7½	0 8½
Common and short	,,	0 6	0 7½
Ox and Cow, on the skin	,,	0 7	0 7½
Ditto clean and free of	,,	0 8	0 8¾
Russian long combed	,,	2 0	2 2
2d quality	,,	0 9	0 10
Short	,,	0 6	0 7
Horns.			
Cape	per 123	48 0	86 0
B. Ayres, M. Video, & Rio J. Ox	,,	26 0	45 0
Small Ox and Cow	,,	12 0	24 0
Buffalo	per cwt.	16 0	38 0
Deer	,,	24 0	35 0
Tips—Buenos Ayres	,,	18 0	22 0
North American	,,	18 0	20 0
Buffalo	,,	17 0	22 0
Bones.		£ s. d.	£ s. d.
River Plate	per ton	4 10 0	6 10 0

used), it certainly does appear to be a circuitous as well as costly method of getting an acid by the decomposition of tannin.

Oak-bark is the most important tanning material in common use. [See BARK.] It must be stripped in spring, for it then contains more tannin than bark cut in autumn, and this again more than that which is taken in winter. The trees are felled about May: but in some cases, a small quantity is cut down about two months later: this is called *midsummer bark*, but it is now seldom seen in the market. The quantity of tannin is considered by tanners to be in proportion to the freedom with which the sap flows at the time of stripping, and to the facility with which the bark is removed. Bark which has the appearance of having been removed with difficulty, fetches a lower price than that which appears to have come off with ease. The richest bark is obtained in the warmest spring, for then the sap is most abundant. A few days of cold previous to the felling and stripping reduces the proportion of tannin and sap. The bark of coppice trees about 12 years old contains more tan than younger trees, and these more than old ones. According to Stenhouse, the tannin of oak-bark when subject to destructive distillation does not afford pyrogallic acid, as the tannin of gall nuts does: hence the tannin of bark is probably not identical with that of galls. Oak-bark contains from 5·6 to 6·0 per cent. of tannin, and in this as in other astringent barks the tannin is contained solely in the inner white layers next the alburnum, the middle coloured portion containing most of the extractive matters, and the epidermis or exterior but little extractive and no tannin. From 4 to 6 lbs. of oak-bark are required for the production of 1lb. of leather. Leather tanned with oak-bark is considered superior to that made with any other tanning material, but the process is slower. The price of good English oak-bark per load of 45 cwt. delivered in London in June 1852, varied from 12*l.* to 13*l.* 10*s.*[1]

Sumach is used in the manufacture of the lighter and finer kinds of leather. It consists of the powder of the leaves and young branches of shrubs growing in the south of Europe and known to botanists as *Rhus cotinus*, *Venus sumach*, or the wild olive; *Rhus coriaria*, hide or elm-leaved sumach. The former is used most extensively by the dyer and calico printer; the latter by the tanner. Of late years sumach leaves have been imported entire in consequence of the adulteration which formerly prevailed. Its per-centage of tannin has been found to vary from 16·4 and 16·2 in Malaga and Sicilian specimens, to 10, and 5 in Virginia and Carolina sumach. The tannin appears to be identical with that of galls, and a good deal of gallic acid exists ready formed in sumach. When mixed with water it is more apt to ferment than any other tanning material. The price of Sicilian sumach in June 1852 was from 14*s.* 6*d.* to 16*s.* per cwt.

(1) When the bark has been stripped, the long pieces are set up on end (*stacked*) to dry. In the present year, 1852, after the stacking, a succession of three weeks' rain greatly deteriorated the bark, by washing out a portion of the tannin

Divi or *divi-divi* is the pod of a leguminous shrub, *Cæsalpin coriaria*, a native of South America, and growing to the height of 20 or 30 feet. It is imported into Great Britain from the West Indies, and from various parts of the north coast of South America. The pods are of a dark brown colour, about 3 inches long, but curled up as if by heat in drying. The whole of the tannin exists in the rind below the epidermis: the taste is highly astringent and bitter, but the inner skin, which encloses a few flat seeds, is nearly tasteless. Divi contains a considerable quantity of tannin, and also a mucilaginous substance which prevents its being used in dyeing and calico printing. It soon ferments when mixed with water. The leather made by means of divi is very porous, and is of a brown or deep brownish red colour. The colouring matter is produced somewhat suddenly, and appears to be the result of fermentation. If air be excluded the colour is not produced and the leather is equally good. The price is from 8*l.* to 9*l.* per ton.

Valonia consists of the acorn-cups of *Quercus Ægilops*, or prickly-cupped oak, growing in the Morea. As soon as the acorns are gathered they are partially dried, and conveyed by mules to Smyrna for shipment. They are here stored in warehouses for some months, in layers of from 3 to 5 feet in thickness. The cups undergo a slight fermentation, and in drying, the long spreading scales which confined the acorn contract, and allow the acorn to fall from the cup. The acorns which contain no tannin are separated from the cups, and those of the latter which are damaged are also picked out. The diameter of the cups including the scales is a little under 2 inches. A smaller kind of valonia, *camata*, bears a higher price than the common: it is somewhat richer in tannin, and is chiefly used by the silk dyers. Good valonia is thick, full grown, and bright in colour. If exposed to rain after being gathered the cups lose a portion of their tannin and become of a deeper colour. About 2 lbs. of valonia are required for the production of 1 lb. of leather, which is said to be less permeable to water than that made with oak-bark, and so heavy as to make valonia the cheapest of all tanning materials, except catechu or terra. A mixture of valonia and oak-bark may be used with good effect.

Catechu, *cutch*, *terra-japonica* and *terra*, are inspissated aqueous extracts from the bark, wood, and probably the leaves of the *acacia catechu* and *Uncaria gambir.* In commerce, the two sorts are known as *Catechu*, or *Gambier*, and *Cutch.* Most of the catechu from Bombay is said to be from the former tree, and that from Bengal from the latter. Bombay catechu or cutch is the richer in tannin; it is of a dark brownish red colour, internally as well as externally, and of specific gravity 1·38. Bengal catechu or terra is of a light brown colour internally: its specific gravity is 1·28. Both are astringent and bitter, leaving a sweetish taste on the palate.

Catechu is said to be prepared by felling the tree, cutting it up into small pieces, and boiling with water in a narrow mouthed vessel until only one-half of the original bulk of liquid remains. The solu-

tion is then transferred to a wide earthen vessel, in which the evaporation is continued: the inspissation is completed by exposure to the sun with occasional stirring. Before the extract is quite dry it is placed in cloths, strewed over with the ashes of cow-dung, cut into small lumps and again exposed to the sun. Mr. Parnell remarks that the appearance of the dark-coloured variety, or cutch, answers better to the description of this mode of preparation than that of the light-coloured variety. This, which is more pulverulent than the former, is said to be prepared by mixing the concentrated decoction of the tree with a pulverulent substance resembling starch. This powder is disposed in a thin layer on a floor or shelf, and the concentrated infusion or decoction allowed to run over the floor, and be imbibed by the powder. When the mass is become stiff by drying, it is cut up into small lumps and dried in the sun. Both kinds of catechu contain about half their weight of tannin, which differs from that of galls in affording olive green precipitates with salts of iron, and yielding no pyrogallic acid on destructive distillation. The tannin of catechu is soluble in cold water. Catechu also affords a peculiar principle, which has been named *catechin* and *catechuic acid*, which is not soluble in cold water, but slightly so in the solution of the tannin of catechu. Catechu is extensively used in India in tanning, and of late years has also been much used in this country. It tans the skins with great rapidity, but the leather is light, spongy, permeable to water, and of a dark reddish fawn colour. The light-coloured variety of catechu produces a softer leather than that tanned with cutch. Catechu produces but little of the deposit of *bloom* which is yielded by oak-bark, valonia, and divi. A pound of catechu is said to be sufficient for the production of about a pound of leather.

Catechu is used by calico printers, to produce a fast bronze on cotton fabrics.

Myrobalams.—The substance known by this name is the fruit of several East Indian trees, and is used in India as a substitute for galls. When ripe, the fruit is pear-shaped, deeply wrinkled, and of a brownish yellow colour: it weighs from 70 to 100 grains. The husk contains the whole of the astringent matter, some mucilage, and a brownish yellow colouring substance, which is used in India for dyeing yellow. The husk is easily separated by bruising the nut, which it encloses. The tannin of myrobalams differs slightly from that of galls. Gallic acid is also present in rather large proportion. The price of myrobalams in June 1852 was quoted at from 6*l.* to 10*l.* per ton.

Mimosa, or *Wattle-bark*, is procured from different species of mimosa, which grow in Australia and New Zealand. It is sometimes imported in the form of fluid extract, as well as bark. The leather produced by its means is of good quality, but of bad colour. The bark must be finely ground, or it does not give up the whole of its tannin to warm water.

Cork-tree bark.—The outer dead bark of the cork oak, known as *cork*, may be removed without injury to the tree, [see CORK,] but the inner bark which is used in tanning cannot be removed without destroying the tree. In Corsica, Spain, and a few other countries, where the tree is abundant, the bark is removed for tanning. This bark contains twice as much tannin as oak-bark of average quality. The tannin appears to resemble that of catechu: it affords scarcely any bloom, and gives a dark colour to the leather.

Larch bark is sometimes used as a substitute for oak bark, for tanning the inferior sheep skins, known as *basils*. It contains a good deal of tannin, mucilage, and some resin.

Willow bark.—The bark of the common willow contains, according to Davy, 2·3 per cent. of tannin, and that of the Leicester willow 6·8 per cent. Danish leather, which has a peculiar and agreeable odour, and is used for making gloves, is prepared from kid and lamb skin, by means of willow bark. The same bark is also used in the preparation of Russia leather, but the odour of that leather is produced by the oil of birch-tree bark.[1]

The following table is from a more elaborate one, constructed by Sir H. Davy, to show the value to the tanner of the different substances named. The numbers express the relative quantities of dry hides capable of being tanned by equal weights of the materials:—

Bombay Catechu	261
Bengal ditto	231
Nut galls	127
White inner bark of Leicester willow	79
Sicilian sumach	78
White inner bark of young oak	77
——— old oak	72
——— Spanish chestnut	63
Souchong Tea	48
Green Tea	41
Entire bark of Leicester willow	33
——— oak	29
——— Spanish chestnut	21
Middle bark of oak	19
——— Leicester willow	16
——— Spanish chestnut	14
Entire bark of elm	13
——— Common willow	11

Mr. Parnell very properly remarks, that "if the tannin and all the other ingredients of these astringent matters were of precisely the same nature, such a table as the above might exactly indicate the respective values of the different substances. But

(1) The following extract from Messrs. Goad & Rigg's Prices Current for 1851, will show the sources and prices of the imported barks. They are all free of duty.

	£	s.		£	s.
Oak Bark—					
Flemish ......per ton.	5	0	—	7	0
Dutch ...... ,, ,,	4	5	—	5	10
German ...... ,, ,,	4	10	—	5	10
Cork Tree Bark—					
Spanish ...... ,, ,,	7	0	—	8	0
Leghorn ...... ,, ,,	6	0	—	7	0
Mimosa Bark ...... ,, ,,	8	10	—	9	10
Gambier [Terra Japonica] ,, ,,	16	10			
Divi Divi—					
Savanilla ...... ,, ,,	8	0	—	9	0
Maracaibo ...... ,, ,,	none.				
Valonia—					
Smyrna ...... ,, ,,	14	0	—	15	0
Morea ...... ,, ,,	10	0	—	12	0
Camata ...... ,, ,,	14	0	—	16	0

the tanner has to take cognisance of other circumstances than the actual proportion of astringent matter contained in his material; for it is well known that a considerable difference may be detected in the quality of leather made from similar skins, and in the same manner, but with different vegetable matters, though the leather be perfectly tanned; this can only be ascribed to a difference in the nature of the tannin, or the accompanying mucilaginous and other matters. The leather produced by means of larch-bark, for example, is far inferior to that made with oak-bark, though similar skins be operated on, and the tanning be continued the same length of time; and catechu and divi produce a more porous leather than oak-bark or valonia. The quantity of colouring matter present in the tanning material, and the susceptibility of the latter to produce a soluble colouring matter on exposure to the air, form another important subject for the consideration of the tanner. The quality of the leather may not be in the least affected by the attachment of vegetable colouring matters; but the prejudice of purchasers requires that both upper and sole leather should possess a uniform dull fawn colour, or what is still more preferred, a yellowish fawn colour. The infusions of several of the tanning materials, which have been recently introduced, either contain, when first made, or afford on exposure to the air, dark reddish brown colouring matters, which become permanently attached to the leather. The slow conversion of tannin into gallic acid, by exposure to the air, is generally, and probably always, attended with the formation of a dark brown substance, (the apothème of Berzelius,) sufficiently soluble in water to colour the leather throughout its entire thickness. The principal objection to the use of the cork-tree bark, consists in the presence of such a colouring matter as this in the infusion of the bark, particularly after it has been freely exposed to the air; and light catechu and cutch, though generally about twice the price of oak-bark, would be esteemed cheaper than any other tanning material, were it not for the reddish brown colour which they communicate to the leather. Although the recent infusions of all vegetable tanning materials contain more or less of this apothème, yet there can be no doubt that the quantity is greatly increased by a free exposure to the air: hence another reason for protecting the pits as much as possible from all oxidating influences."

In order that the tanner may estimate the values of different kinds of bark, or of different varieties of the same bark, he must be able to determine the proportion of tannin in each specimen; but this is not easily done. The usual test for tannin, as already stated, is some form of gelatine, such as glue or isinglass, a solution of which is mixed with a known weight of tanning material, also in the state of solution; the precipitate of tanno-gelatine is then weighed, and the proportion of tannin thus ascertained. Such a result, however, is not trustworthy, because the composition of tanno-gelatine varies with the strength of the solution either of gelatine or of tannin, and some varieties of tannin produce larger precipitates with gelatine than other kinds. Thus, an infusion of cork-tree bark, or of cutch, affords a smaller precipitate than an infusion of gall nuts of similar strength. A better test than the above is said to be sulphate of quinine, the solution to be acidulated with a few drops of sulphuric acid; this, it is said, will precipitate tannin from its solution perfectly, and the composition of the precipitate is constant. The tanner is accustomed to use a kind of hydrometer, called a *barkometer*, for ascertaining the strength of his infusions of bark, or *ooze*, as they are called. The instrument is graduated by the standard of pure water, and an ooze is said to be strong or weak according as the stem of the instrument rises above or sinks below the water mark. Now as the ooze, in addition to the tannin, contains colouring matters in solution, and these vary in different barks, and in some of the new tanning materials are abundant, it is obvious that no method of taking the specific gravities of infusions of bark, will afford correct indications of the amount of tannin contained in them. The tanner judges of the strength of ooze by its taste, which in strong oozes is highly astringent. Perhaps the best method of judging of the value of a tanning material, is to take a piece of perfectly dry prepared hide, or skin, and digest it in a known quantity of infusion of the tanning material which is to be tested, until all the tannin &c. shall have separated. The skin is then taken out, slightly washed, dried and weighed. The increase of weight is the weight of tannin and other matters required. An experiment of this kind may be performed in the course of a few hours, if the skin be pared thin, and a gentle heat be employed: there should be a slight excess of tannin in the infusion, in order that the skin may be saturated with tannin.

Section III.—Preparation of the Skins for Tanning.

When hides are received fresh from the slaughter house, they are washed, if water be abundant; and the horns are removed for the comb maker. Dried or salted skins are soaked in water for 10 or 14 days, with occasional friction, and in some cases a kind of fulling-mill is used to produce that soft supple state which is necessary for the working. After the washing, green hides are worked with a knife on the flesh side, to get rid of flesh and fatty matters. Salted hides are occasionally scraped at this stage, but dried hides do not require this treatment.

The next operation is to get rid of the hair and scarf skin, for which purpose the hides are put into oblong troughs, or pits, sunk in the earth, and containing a mixture of lime and water of 3 or 4 different strengths, in the different pits. They are left for a day or two in the weakest, and then transferred to the others in succession, until, in the course of two or three weeks, depending on the texture of the hide and the state of the atmosphere, the lime has dissolved the hair sheath, and combined with the fat of the hide, to form an insoluble soap. The hides are *handled* every day, to equalize the action of the lime,

Handling is a term in common use in the tan yard; it consists in taking the hides up out of the pit, and allowing them to drain in a heap for an hour or two, when they are returned to the pit. The lime water is stirred up before the introduction of the hides, so that solid particles of lime may cover the surface.

When the hair and epidermis yield to the touch, the skins are taken out, and scraped upon a cylindrical table, called the *beam*, with a curved two-handled iron scraper, called the *unhairing knife;* it is concave, and fits the curvature of the beam; the

Fig. 1288. UNHAIRING HIDES.

hair comes off easily, leaving what is called the *grain* of the skin. The hide is then *fleshed*, that is, the beam man passes a knife, called the *fleshing knife*, over the inner surface, for completing the removal of flesh and fat. This knife is convex, and its edge being sharp, the operation is that of *cutting*, not *scraping*, as in the process of unhairing. It requires great skill to shave or plane off the flesh and fat down to the surface of the true skin, and yet not to cut it. After being thoroughly washed in water, and again scraped to get rid of the lime, the ears and other projecting portions are cut off for the glue maker; the hides are then fit for the tan-pit. They are, however, sorted, to separate those which are sound from those which contain *warble*, or *wurmal holes*, formed by the larvæ of a species of gad-fly, (*Œstrus bovis*,) which deposits its eggs in the hide of the ox. Hides containing these *bot-holes* make very good sole-leather, but cannot, of course, be used for hose or bucket leather, or for foundry bellows, and similar purposes.

The use of lime has many disadvantages; it dissolves a portion of the membrane which would make good leather, renders the surface unequal, and the action of the tan uncertain. Hence many attempts have been made to get rid of this material. By one method they are hung up in a *smoke house*, or close room, heated a little above the ordinary temperature by means of a smouldering fire, fed with spent tan, which produces no flame. Here the hides enter into incipient fermentation, which softens the epidermis and roots of the hair. In Germany, with the same view, the hides are piled up in a heap, and covered with spent tan: in a short time they begin to putrefy, and without great care are liable to be spoiled. By another plan, they are piled up on a bed of litter, and covered with litter for twenty-four hours: then turned over, and afterwards frequently examined to see when they are fit for unhairing, These plans are said to be more objectionable than limeing. In France small quantities of salt are added, to prevent the putrefaction of the gelatinous tissues, but not sufficient to retard that of the hair-sheath and epidermis. In some parts of the United States of America, the hides are exposed to confined air, kept damp by the spray of water, and it is said that in from 6 to 12 days the hair comes off easily. It is stated that no putrefaction takes place, the effect being attributed solely to the softening action of moisture. The grease must be got rid of in some other way, for it is one of the uses of the lime to combine with it to form a soap, as already noticed.

Dilute acids serve the same purpose as lime, and are used in some tanneries; sulphuric acid, very dilute; sour milk; pyroligneous acid; fermented barley, rye water, and bran, are all in use; the two latter are sometimes applied to the skins after the limeing. Dilute acids have the effect of swelling the pores of the skins, so as to enable the tan liquor to penetrate them more easily. When this operation is performed, it is called *raising*, and a common solution for the purpose is made by the addition of 1 part oil of vitriol, and 1,000 parts water; a moderate heat being applied, the raising is completed in 24 hours. Oxalic and tartaric acids are better raisers than sulphuric, but much more expensive.

In kips and skins all the lime must be removed, or a hard leather will be the result. After limeing, they are exposed to an alkaline solution, called *bate*, or *grainer*, consisting of the dung of hens, pigeons, and other domestic birds, in which they remain 8 days, according to the temperature. During this time they are frequently stirred, and also taken out and scraped on the beam. 10 or 12 gallons of dung are sufficient for *bating* 100 skins. By this process they are made soft and pliant, and the lime is almost completely separated. For morocco, dog's dung (formerly called *album Græcum*) is also used for the purpose. It was supposed that the lithic acid of the dung combined with the lime, and that the ammonia produced by the putrefaction of the mixture formed a soap with any remaining fat of the hide. It is more probable, however, that muriate of ammonia is the most active constituent of the dung; which, by dissolving a portion of uncombined lime, forms chloride of calcium, and free ammonia. The animal matters of the dung dissolve a portion of the gelatinous tissue, and in warm weather the grain is discoloured from this cause. The process of bating is disgusting, and its present imperfect condition is not creditable to our chemists. Something, however, has been done. In 1840 Mr. Robert Warington proposed carbonate of ammonia as a bate; this does not dissolve the lime out of the

skin, but destroys its causticity, by converting it into carbonate of lime. Bran water is the bate for sheep skins.

Section IV.—The Process of Tanning.

The tan-yard usually occupies a considerable extent of ground, and above it are lofts for drying the tanned leather. The tan-pits, which are formed in the earth, are oblong in shape, from 6 to 8 feet in depth. In forming a tan-pit the whole ground is first excavated, and covered with clay; the boards which form the lining to each pit are first built up into chests, then adjusted in their places, and filled with earth to weight them down; the various pipes for conveying the ooze are next arranged and fixed, and lastly, the spaces between the wooden chests are filled up with clay, and made level with the surface of the ground, producing the appearance of a number of pits, in rows side by side, with narrow spaces between them for the convenience of the workmen. In Fig. 1289 these spaces are made wider than is usual in the modern practice.

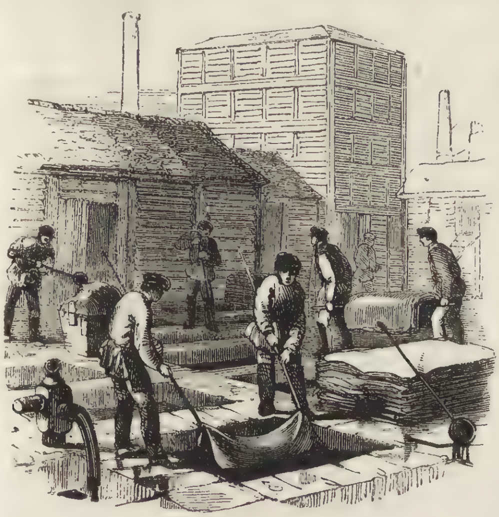


Fig. 1289. TAN-YARD.

The oak-bark is ground in a mill attached to the yard, and the ooze is generally prepared before it is brought into contact with the skins. By the old method it was made in the pits where the hides were impregnated, the ground bark and hides being laid in alternate layers in the tan-pit, which was then filled up with water. When the ooze appeared to be spent, the pit was emptied and refilled with fresh bark and water, and so on many times. By this process, which was spread over as much as 15 months, a very superior leather was produced.

According to another of the old plans, a layer of spent bark 6 inches thick was spread over the bottom of the pit; upon which was placed a layer of fresh bark finely ground, 1 inch thick; upon this was spread a hide quite flat; then another layer of fresh bark, then another hide; then another layer of fresh bark, and so on until the pit was filled; the whole was then covered with a stratum of bark 6 inches thick, called the *hat:* the whole was then well trodden down, and in some cases planks laden with heavy stones were imposed. The pit was left in this state for 2 or 3 months, when it was emptied, the hides stretched and re-arranged in the pit with fresh layers of bark. The process was again repeated 3 or 4 months later, and lastly the pit was filled up with strong ooze, which completed the process. This slow method was sometimes varied by pouring a little water into the bottom of the pit, the vapour of which assisted the absorption of the tannin. But the more usual plan was to fill the pit with soft water after the above arrangement was made, and at the last filling to use ooze instead of water.

In the modern practice of tanning ooze instead of water is used at every stage: the hides are more rapidly impregnated, and stronger oozes are employed than formerly. The ooze is prepared by passing cold water through a stratum of the powdered bark or other astringent matter, until, by successive infiltrations, it is deprived of all its ingredients which are soluble in cold water. Some tanners make their ooze with hot or lukewarm water, for which purpose steam is introduced by a large iron pipe to the bottom of a deep pit containing a mixture of the vegetable matter in water. A little above the true bottom is a false bottom, through which the infusion filters into the space below, from which it is withdrawn by a pump. According to another method, water is first applied to nearly exhausted bark, which is digested in it for a long time at a moderate heat: the weak ooze thus formed is pumped into a pit containing more bark not so much spent as that in the first pit. From this second pit it is transferred to another containing richer bark, and so on through several pits until it arrives at a pit containing fresh ground bark, and from this the ooze is withdrawn for use.

It is a common practice to introduce the skins into a nearly spent ooze, and to remove them into oozes of gradually increasing strength. Oozes are of two kinds according to their strength, viz. *handler liquor* and *layer liquor*. The tanning is completed in the handlers, and the stronger oozes or layers are used to produce the deposit of *bloom.*

The skins are usually arranged in horizontal layers for economy of space, but a few tanners prefer to suspend them vertically. Some use oozes only; others introduce a little ground bark. If oozes only are used, the skins are at first handled once or twice a-day in the first ooze, every second day in stronger handlers, and afterwards about once a-month in the layers. In the process of handling, the hides are taken out by two men one at a time, by means of blunt pointed hooks furnished with long handles, (see Fig. 1289,) and are placed regularly one on another, on a sloping wooden rack placed over the adjacent pit; they are left to drain for one or two hours, and are then returned to the pit, the last hide taken out being the first to be returned.

Chemistry has not done much for the tanner except to discover a variety of new tanning materials, none of which, however, appear to be equal to the ancient material, oak-bark. The tanners themselves have endeavoured to abridge the long, costly and tedious

process of tanning thick leather. These attempts have not been very successful, but we may notice a few of them. In the process by Mr. Cagswell, an American tanner, the hides or skins are placed upon layers of saw-dust or other soft porous material contained in shallow rectangular boxes; these are arranged one about a foot over the one below: the edges of the hides are raised a little, so as to convert each into a shallow trough, into which the ooze is admitted. As the ooze becomes exhausted and filters through the hide and the saw-dust, it passes off by a channel in the bottom of the box, and the hide is refilled with fresh ooze. This plan, which gets rid of the labour of handling, is said to be expeditious, but it is necessary, to complete the tanning of the edges, to put the skins into pits for three or four weeks, which, of course, is an objection.

The labour of handling is also got rid of by arranging the skins vertically, for which purpose they are attached at the edges to a horizontal wooden frame suspended by pulleys and ropes, and are thus lowered into or raised out of the tan-pit all at once.

A quick method of tanning was patented by Spilsbury in 1823. The hides having been unhaired and cleaned, are carefully examined to see that they are sound, and if any holes exist they are carefully sewn up. A hide is then stretched across a rectangular frame, and upon this hide is placed another frame secured by screws and bolts: upon this is placed a second hide and then another frame similarly secured, this system of framing forming a flat water-tight vessel bounded by the two hides; the whole is then placed in a vertical position, and ooze admitted into the cavity between the two hides by a pipe leading from an elevated cistern, the air being let out by a stop-cock in the frame. The hydrostatic pressure forces the ooze through the pores of the hides by a process of slow infiltration. When the tanning is completed, the supply of ooze is cut off, the liquor drawn off, the bolts are unscrewed, and the frames removed: the compressed edges of the hides are clipped off, and the hides finished in the ordinary manner.

In Drake's patent process the hides are sewed together so as to form a water-tight bag, which is filled with ooze, and to prevent the sides from bulging out, the bag is placed between two vertical racks. The ooze slowly escapes to the outside, and is returned to the bag. As the tanning advances the temperature of the room is raised to facilitate the evaporation from the surface, and thus to promote the percolation. The pressure of the racks made the texture of the leather unequal, a defect which was remedied by Chaplin, but the plan was not successful. An attempt was made to imitate the old Danish process, viz. to keep the bags full of ooze immersed in pits full of ooze; but the great space thus required was an objection, and is now, we believe, only practised in tanning small skins with sumach.

Air-tight vessels have been tried, from which the air has been pumped out after the skins were arranged in them; ooze was then admitted, and forced into the pores by hydrostatic pressure; the operation being repeated from time to time with stronger oozes. The abundant evolution of air, or of some other gases from the tanning liquor, defeated this plan.

Mr. Herapath of Bristol took out a patent for a new process of tanning, some years ago. According to that gentleman, the great obstruction to rapid tanning is, that the skins retain so much of the spent ooze, that when placed in a stronger one, the latter cannot enter the pores already saturated with water, except after weeks or months of maceration, during which time the exchange is being slowly made. By the new plan, in passing the skins from a weak to a stronger ooze, they are compressed between rollers, a pair of which is erected over each pit. The lower roller is about 30 inches in diameter, and is covered with horse-hair cloth: the upper roller, which is loaded, is about 18 inches in diameter, and is covered with woollen cloth. 50 hides are introduced into each pit; these are sewed together with twine, so as to form an endless band, which is introduced between the rollers, and as these rotate, the hides are successively lifted from the bottom of the pit, and then returned into it for a fresh supply of ooze. Mr. Herapath states that each ooze becomes exhausted about 2° of the barkometer in 24 hours, when it is pumped into the next pit of the series, and fresh ooze introduced. It is said, that by this process a strong hide may be completely tanned in 6 or 8 weeks, and calf skins and kips in from 20 to 30 days. Butts can be finished in 4 months, and the increase in the weight of leather, as compared with that made in the usual way, is stated to be as 34 lbs. to 24 lbs. The leather thus prepared is said to be hard and brittle, an objection which applies to all the quick processes.

Mr. Squire, of Warrington, has invented a process which is, perhaps, the least exceptionable of all the quick methods. The hides and skins are introduced into a horizontal wooden cylinder, 10 feet long, and 5 feet in diameter, four-fifths filled with hides and ooze. This cylinder is made to rotate on an axis, at the rate of 6 or 8 revolutions per minute. The interior of the drum is furnished with projecting ridges, which increase the agitation and prevent the hides from rolling into balls. A hot ooze, and fresh tanning material is used in this process. This soon becomes spent when the drum is opened, and fresh materials are introduced. It is of importance not to neglect this at the proper time, since spent tan liquor is very injurious to leather. The advantages of this process are—1, the agitation of the skins; 2, the use of a warm ooze; 3, the exclusion of atmospheric air; and 4, the rapidity of the process, 14 days sufficing for the tanning of thick kips. The exclusion of the air prevents the deposit of colouring matters on the leather—even divi can be used without such a result; whereas, in open pits a reddish colour would be imparted, such as would make the leather unsaleable. In this process the leather is rather deficient in bloom. What is this bloom, and what is its use? These questions have not been satisfactorily answered

either by the chemist or the tanner. It is a test by which the purchaser judges of the value of the leather, for a good deposit of bloom cannot be obtained unless a considerable time be allowed for the tanning. Most of the new tanning materials produce a different bloom from that of oak bark; while others yield hardly any bloom at all. All leather prepared by the slow process, contains a considerable quantity of tannin more than is necessary for the complete saturation of the gelatinous tissue. This surplus tannin is not chemically combined, but only mechanically attached to the exterior of the fibres. By digesting chippings of leather in water, some of this mechanically attached tannin may be dissolved out. In the processes of *finishing* sole leather, about to be described, it is possible, as Mr. Parnell suggests, that ellagic acid is formed, and it is this substance which forms the bloom. When catechu is employed as the tanning material, the bloom is then said to consist of catechuic acid, which forms the greater portion of that part of the catechu which is insoluble in cold water.

In the course of the 9 to 15 months required for tanning hides, the whole of the skin or dermis disappears by successive formations of the compound of gelatine and tannin, on both sides of the hide, until all traces of the animal substance disappear. In an early stage, a thick whitish line is seen on cutting across a hide; this is a portion of the skin itself: but as the process proceeds, this also disappears, and the tanner knows that the process is complete When the hides are taken out of the last bloomer pit, they are slightly washed in water, drained, and suspended from poles in airy lofts to dry; once or twice during the drying each skin is placed upon a

Fig. 1290. STRIKING HIDES.

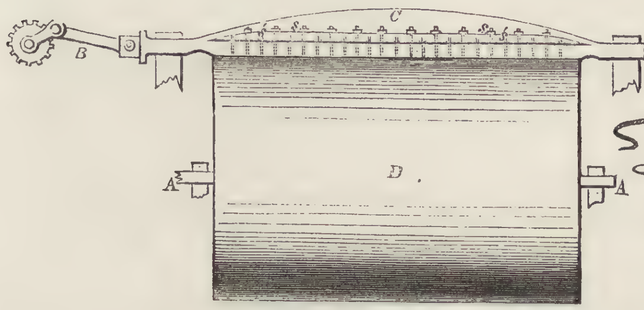
long cylindrical horse, and *struck* or smoothed with a triangular steel knife, the surface being occasionally sprinkled with a bunch of butcher's broom dipped in water. This brings the bloom up to the surface. Of late years the bloom has been struck off so as to produce a ruddy fawn colour, which is now preferred for sole leather. The hides are next condensed under a roller, about 6 inches in diameter, loaded with from 10 to 13 cwt.: this operation is shown in Fig. 1291. In some places the hides are hammered on a block, with a wide-faced hammer. In France the hammer is arranged like the tilt-hammer used in the manufacture of steel. The leather is now *finished*, and fit for the market.

Fig. 1291. ROLLING HIDES.

Bordier has invented a method of preparing leather by the use of metallic, or earthy, instead of vegetable substances, by means of which it is stated that thick sole leather of durable quality may be prepared in a remarkably short time. After washing, unhairing, and swelling the hides, they are submitted to the action of the metallic solution; this consists of the sub-sulphate of the peroxide of iron, or sulphuric acid and peroxide of iron, the latter being in excess. One method of preparing the solution is as follows:—2 cwt. of bruised copperas are dissolved in 15 gallons of boiling water, in a copper boiler. The liquor is run off into a shallow underback, of the capacity of 44 gallons, and then mixed with 44 lbs. of sulphuric acid, (sp. gr. 1·848.) This is agitated with 44 lbs. of black oxide of manganese in powder, gradually added. The agitation is continued until gas ceases to be disengaged, and afterwards at intervals until cold. The solution is then diluted with water to any strength required. The hides and skins digested in this liquor gradually become impregnated throughout with an insoluble sub-sulphate of peroxide of iron, while free sulphuric acid, sulphate of manganese, and a little proto-sulphate of iron, or copperas, remain in the liquor. In from 6 to 8 days for hides, and 3 to 4 for skins, the animal fibre is rendered completely imputrescible, and a leather is produced as impermeable to water as that tanned by the ordinary method. The finishing processes are similar.

For certain special purposes the hides are split into two portions, after having been immersed in a weak ooze for 10 or 14 days. Each half is then tanned separately, and the upper, or grain half, is used for covering the roof and sides of broughams and other carriages, the flesh half is used for making enamelled leather for shoes, &c. The *splitting machine* shown in section and elevation, Figs. 1292, 1293, consists of a mahogany cylinder or drum, D D, 6 feet in length, and 4 feet in diameter. A slot

shown at *w* runs the whole length of the cylinder; in this slot the tail end of the hide is fastened by small wooden wedges *w*. The knife *k* is a plate of steel about $\frac{1}{4}$ inch thick, and of the same length as the cylinder. It is attached by means of screws *s s*, to the bottom of a firm cast-iron carriage C; *s′ s′* are set-screws for setting the edge of the knife straight. A quick alternate motion is imparted to the carriage by means of a crank B. While the knife vibrates rapidly backwards and forwards in a plane parallel to the axis A of the drum D, the drum is made to revolve slowly upon its axis, and drags the hide with it. The hide is kept flat to the cylinder by means of the governor G, which is a bent thin plate of steel, extending the whole length of the knife and in front of it, and by its pressure, which it receives from a



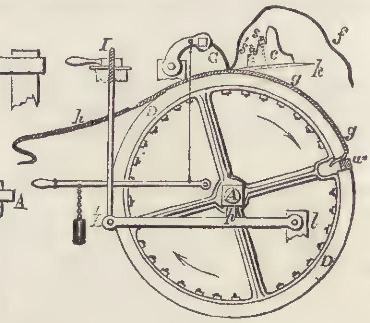


Fig. 1292. ELEVATION AND SECTION OF HIDE-SPLITTING MACHINE. *Fig.* 1293.

weighted lever, smoothes out all wrinkles. In fact, the cylinder drags the hide under the governor, which acts similarly to a *slicker*, although it is quite stationary. As the hide *h* is split, one half *f*, which is the split flesh side, passes over the knife; the other half, or the split grain side *g*, continues to adhere to the drum. A screw at I, at each end of the drum, is used to vary the thickness of the split; the screw acts upon a lever L′ *l*, which, by means of a pin *p*, raises or depresses the axis of the cylinder, and consequently diminishes or increases the thickness of the split grain side of the hide. Fig. 1294 represents the appearance of the machine with the men superintending the operation.

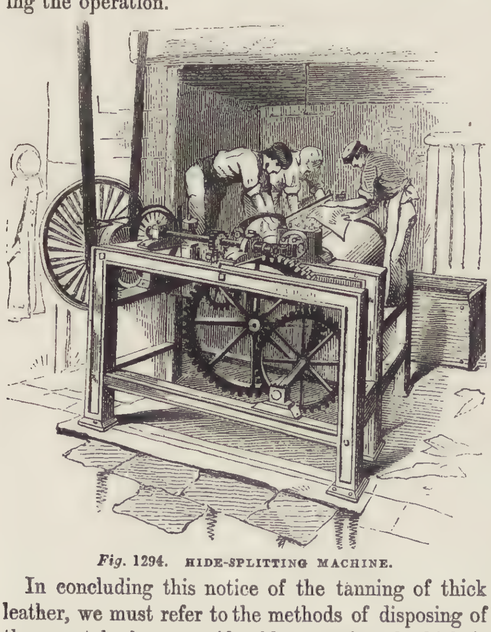


Fig. 1294. HIDE-SPLITTING MACHINE.

In concluding this notice of the tanning of thick leather, we must refer to the methods of disposing of the spent bark, a considerable quantity of which is produced in every large tan yard. It is formed into cakes by pressure in iron moulds, and sold in London as a cheap fuel, under the name of *turf*. It also supplies the place of the more expensive article straw, which is often thrown down in the streets of London, opposite the houses of sick persons, for the purpose of deadening the noise of carriages. It is also used for forming hot-beds; when collected in a heap, it ferments slowly, and forms a fine vegetable mould. Most of the pine apples of this country are grown in a compost, into which the spent bark largely enters. After having served its purpose in the hot-bed, it is used as a manure by the farmer. At the tan-yard of Messrs. Hepburn, (where the Editor has received much assistance in the preparation of this article,) steam-power is used, and the spent bark is employed as fuel in raising the steam, for which purpose the bark, arranged in layers between iron plates in a large case, is submitted to the action of a hydrostatic press, whereby the moisture is expelled, and solid cakes are produced, which make good fuel. The liquid pressed out by such powerful means must be rich in alkaline matter, and we have no doubt that if collected and properly treated, a good crop of potash salts might be obtained, the waste heat of the boiler being employed in the evaporation.

SECTION V.—CURRYING.

The rough skin of leather is transferred from the tanner to the currier, who, by a series of mechanical operations, transforms it into a smooth, shining, pliable skin, adapted to the purposes of the shoemaker, the coach-maker, the harness-maker, &c. We will trace the operations upon a tanned calf-skin.

The skin is first soaked in water to make it pliable; then taken to the beam, and shaved on the rough flesh side, whereby its thickness is considerably reduced, and the uneven and unequal surface brought to a tolerably smooth and even one. The beam, Fig. 1295, consists of a strong frame of wood, supporting a stout plank, faced with lignum vitæ, and made very smooth; this plank can be set at a greater or less

inclination, and sometimes it is permanently fixed in an upright position. The knife, Fig. 1296, No. 1, which is double-edged, is a stout rectangular blade, about twelve inches long by five wide; but the width

Fig. 1295. THE BEAM.

varies according to the purpose intended. At one end is a straight handle, and at the other a cross handle, in the direction of the plane of the blade. The edge of the knife is brought up by means of a whetstone, and a wire edge is afterwards produced by the tool No. 6, and constantly preserved by means of a steel wire, No. 7, which the beam-man holds between his fingers while using the knife. The skin

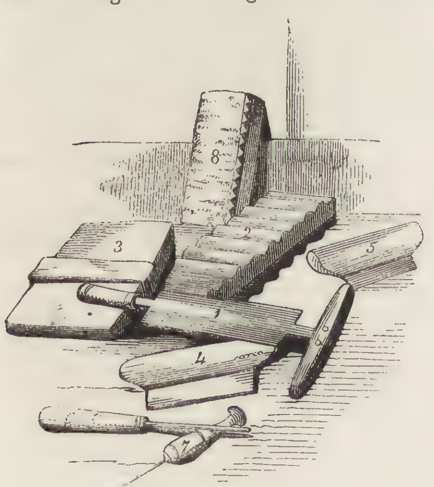


Fig. 1296. CURRIER'S TOOLS.

1. Beam knife. 2. Crippler.
3. Raising board. 4. Glass slicker.
5. Steel slicker. 6. 7. Steels for beam knife.
8. Brush.

being thrown upon the plank, the man presses his body against the skin, to prevent it from slipping; and holding the knife by its two handles, and nearly perpendicular to the leather, he shaves off from the thick parts, and, after every shaving, or two or three shavings, passes a fold between his fingers, and thus ascertains the state of the skin with respect to evenness. When sufficiently reduced by shaving, the skin is again thrown into cold water, scoured, and extended. For this purpose it is placed upon a large table of mahogany or stone, to which the flesh side of the wet skin adheres, and is worked with a tool called the stretching-iron, No. 5; this is a flat rectangular piece of iron, copper, or smooth hard stone, fixed in a handle, with the corners rounded off to prevent injury to the leather; the workman holds this tool with both hands, and, using plenty of water, scrapes the surface with a very strong pressure, especially at those parts where lumps and inequalities appear. By the continued action of this tool the leather is extended or stretched, while at the same time the bloom is brought to the surface.

When the skin is thoroughly cleansed, and all the superfluous moisture has been slicked out, the process of *stuffing*, or *dubbing* (probably a corruption of *daubing*), is performed. Both sides of the skin, but chiefly the flesh side, are smeared or daubed with a mixture of cod-oil and tallow, which is then well rubbed in by means of a brush, or a piece of old sheep-skin with the wool on. The skin is then hung up in a loft to dry; but as the water only evaporates, the greasy substances sink deep into the pores of the leather. In very moist weather the skins are stove-dried.

When the skin is sufficiently dry, it is *boarded*, that is, worked with an instrument called the *pommel*, or graining board, No. 2. The object of this is to bring up the *grain*, that is, to give the leather a *granular* appearance, and also to make it supple. The pommel is a piece of very hard wood, furnished with a strap on the upper side, for the insertion of the hand,[1] and grooved (like a crimping board), on the under side, which is convex. The leather is folded with the grain side in contact, and rubbed strongly on the flesh side with the pommel; this part of the process is called *graining*. It is then extended and rubbed on the grain side; this is called *bruising*. The skin is next taken to the beam and *whitened*, that is, a knife with a very fine edge is passed lightly over it, whereby the flesh side is thoroughly cleaned and brought to a fit state for *waxing*,—a process which is never performed until the skin is required for immediate sale; for, at this part of the process, the currier stores his skins, because they are brought to that state (technically called *finished russet*) in which they can be best preserved. Previous to waxing, the skin is boarded a second time. The first part of the process of waxing consists in laying on the *colour*, or blacking, which is composed of oil, lamp-black, and tallow; the colour is rubbed in thoroughly on the flesh side, by means of a hard brush; it is then *black-sized;* that is, a coat of stiff size and tallow is laid on with a soft brush or a sponge, and well rubbed with a glass of the same shape as a *slicker;* and lastly it receives its final gloss from a little thin size laid on with a sponge. The skin of leather now curried is called *black on the flesh*, or

(1) Hence the origin of the word pommel, from the French *paumelle*, because it clothes the *palm* of the hand.

waxed, in contradistinction to leather which is curried on the hair or grain side, called *black on the grain;* and which is chiefly used for the upper leathers of ladies' shoes; the former, or *waxed* leather, being employed for the upper leathers of men's boots and shoes.

The processes for preparing leather to be blacked on the grain side are similar to those already described, until we come to the process of waxing. *Copperas water*, or *iron liquor*, that is, sulphate of iron dissolved in clean water, or in the water from the tank in which the skins have been soaked, is applied to the grain side of the skin while wet. The iron unites with the gallic acid of the tan, and thus produces an ink dye; the skin is then rubbed over with a brush dipped in stale urine, and when this is dry the stuffing is applied; it is rubbed over with copperas water on the grain side until it is quite black. The grain is then raised, and when quite dry, the skin is whitened, bruised again, and grained in two or three ways; a mixture of oil and tallow is then applied to the grain side, and the currying process is complete.

Section VI.—Preparation of Thin Leather.[1]

In addition to the tan-yard, properly so called, where the thickest and largest skins of leather are made, there are other establishments which contribute extensively to the immense demand for thin leathers; such as *white* and *dyed* leather for gloves, *morocco* of various colours and qualities for coach-lining, book-binding, pocket books, &c., being an imitation of that prepared in Morocco, and other parts of North Africa; *roan* for slippers, &c.; a thin leather called *skiver*, used for hat-linings, and a number of other purposes; and, lastly, *shamoy*, or *wash*-leather.

Of all these varieties, white leather alone is not tanned, but *tawed.* The difference between the two processes is, that the gelatinous tissue is combined with tannin in the one case; and in the other, with something which it imbibes from alum and salt, probably alumina. But, for either process, certain preparations are necessary, whereby hair, wool, grease, &c., are removed, and the skin, thoroughly cleansed, is reduced to the state of simple membrane, called *pelt.*

The preparatory steps vary, according as the skin is covered with wool, or short hair; the one being a valuable commodity, and the other comparatively worthless, its chief use being to mix with mortar. The hair of kid and goat skins &c. is detached by immersing the skins in lime, as already described; but as this plan would injure the wool, a different method is adopted. The wool is usually detached from sheep-skins before they arrive at the tawers. This is done by the great dealers in sheep-skins, called *fell-mongers;* they receive the skins from certain factors, or salesmen, in the skin-market, by whom they are procured from the butchers. The lamb-skins of Italy are imported in casks with the wool on, so that the tawer adopts a process for removing it similar to that employed by the fell-monger. They are first cleansed in water, then scraped on the flesh side, and next hung up in considerable numbers, in the smoke-house already alluded to, where they are *sweated*,—that is, putrefactive fermentation soon commences, a thick filthy slime appears on the surface, and the effect of this is so to loosen the wool, that it can be pulled off easily. Care and judgment are required in regulating the fermentation of the skins, so that their texture be not destroyed. When the wool is removed, the fatty matters are got rid of by a hydrostatic press; a large number of skins being piled up, a considerable quantity of fat is expressed. The skins are then worked at the beam; projecting flaps and rough edges are pared off, and putrefaction is arrested by immersion in lime. They are first put into a nearly exhausted lime-pit, and afterwards into a stronger one, and are frequently worked about with poles. When taken out they are well worked at the beam to get rid of a portion of the lime; and are then immersed in a fermenting mixture of dog's or pigeon's dung, if the skins are to be tanned, and of bran and water if they are to be tawed. During the time that the skins remain in this mixture, they are occasionally taken out and worked at the beam, and are lastly washed in pure water. By such means the pelt becomes a thin extensible white membrane, and is fit for *tanning*, *tawing*, *dyeing*, *oil-dressing*, or *shamoying*.

Tanning with Sumach.—When goat skins are tanned with sumach, and then dyed on the grain side, they form what is called *morocco* leather; but an inferior morocco is prepared from sheep-skin. When the skins are in the state of perfectly clean white pelt, each skin is sewn by its edges into the form of a bag, the grain side out; it is then distended with air, and a mordant of tin, or alum, is applied. The object of forming the skins into bags is to expedite the process, and also to ensure a perfectly equable action of the solution of sumach. If the colour is to be red, the skins are immersed in a warm cochineal bath; indigo is used for blue; orchil for purple, &c.; and they are worked by hand until uniformly dyed. For other colours the pelt is tanned before dyeing. The sumaching is conducted in a large tub, containing a weak and warm solution of sumach. A stronger solution is made in another vessel, and a portion of this, together with some sumach leaves, is poured into the bag, by means of a funnel, through an opening left for the purpose. This is diluted with a quantity of the nearly spent solution in the vat; each skin, after having received its share of the tanning liquid, is handed to a man, who blows into it, and fully distends it: he then ties up the opening, and throws the skin into the vat. About fifty skins are treated in this manner; they all float in the sumach-tub, and are moved about by manual labour, or by machinery, during three hours. They are then taken out, and piled on a sloping shelf by the side of the vat, the mutual pressure thus produced causing the sumach to escape slowly through the pores of the

(1) This and the previous Section are abridged from the Editor's work on the "Useful Arts and Manufactures of Great Britain."

pelt. The bags are being constantly shifted by a man, who watches whether the solution escapes from the seams: if so, he secures them by a few stitches. They are next transferred to a second vat, containing a stronger solution than the first; and here they remain about nine hours, at the end of which time the tanning is complete. The skins are ripped open, rinsed, and drained. The colour of the fine red skins is finished in a weak bath of saffron; and lastly, all the skins, of whatever colour, are stretched upon a smooth sloping board, and *struck,*—that is, scraped and rubbed out, until they become smooth and flat. Sometimes they are sponged on the grain side with linseed oil, in order to promote their glossiness in the subsequent process of currying.

The skins are then removed to a loft, and dried. In drying they assume a horny texture, and are said to be *in the crust.* After this comes the process of currying, or finishing. The skins are again placed upon the smooth sloping board, and rubbed several times with the pommel, and also with a glass ball, cut with smooth sides upon its surface; this polishes them, and makes them firm and compact. The grained, or ribbed appearance, peculiar to morocco leather, is imparted by a ball of box-wood, round the circumference of which are cut a number of narrow ridges. This is passed many times over the skin with a firm pressure, and its effect is not only to improve the surface of the skin, but also to add to its pliability and softness.

The preparation of an imitation morocco from sheep-skins, does not differ essentially from the processes just described; but when the skins are in the state of pelt, they are *split;* that is, every skin is divided into two skins of the same size, but, of course, of only half the thickness of the pelt. This is effected by means of a *skin-splitting machine* which differs in some of its details from that already described. It consists of two rollers, the lower one of solid gun-metal, and the upper one composed of rings of the same material; these cylinders are made to rotate slowly, and between them, but not in contact, is a knife, with a sharp cutting edge, to which a rapid reciprocating motion is imparted. In order to *split* a skin, a man stands on the side of the machine, opposite to the knife edge, and upon the lower or solid roller spreads evenly the end of a skin or pelt; it is caught up by the rollers, and dragged forward against the edge of the knife, by which it is divided; one half going above, and the other below the plane of the blade. During the whole of the operation the man continues to adjust the skin upon the lower roller, the smooth solid surface of which gives support and stability to the skin, while the upper roller, being composed of movable rings, adjusts itself to any unevenness of the membrane. In parts where it is thin, the rings are depressed; where it is thick, they are elevated; hence no part escapes the action of the knife, and no holes are produced in either half. The men are furnished with gloves, to prevent their fingers being caught up by the rollers. About two minutes are occupied in splitting a sheep-skin, during which time the knife is moved to and fro nearly three thousand times. When three or four of these machines are at work in one room, the noise is deafening.

In order to show the precision with which this beautiful machine works, sheep-skins have been split into *three* parts of equal size; the grain side being used for skiver, &c.; the middle for making parchment; while the flesh side was transferred to the glue-maker. The divided skins, or skivers, are sumached in a short time, their thinness rendering the sewing up into bags unnecessary.

Tawing.—The preservation of an animal skin, by means of alum and salt, is called *tawing;* and the object is to employ such materials as will not interfere with the production of a pure white leather. In all the finer kinds of leather-dressing, the perfect purity of the pelt is of the utmost importance, for every particle of dirt, or lime, which is allowed to remain would appear as a speck or a flaw. The purity of the water used for rinsing the skins, is also a point of great importance. At some works, a supply of distilled water is obtained from the boiler to the steam-engine, which is made larger than usual for the purpose.

Kid-skins, for the best kid-leather, and sheep, or lamb-skins, for an inferior sort, being reduced to the state of pelt, the first process in tawing, is to "give them a feeding" with alum and salt. About 3 pounds of alum, and 4 of salt, are used to 120 middle-sized skins. The solution, together with the skins, is put into a drum, or tumbler, to which motion is imparted. The action of the alum and salt upon the skins is not well known, but it is supposed that alumina and gelatine form some definite compound, and that the salt serves to whiten the skins. After some time they are taken out, washed in water, and then put into bran and water, where they are allowed to ferment, till the superfluous alum and salt are removed, and the thickness produced by them is reduced. They are next transferred to the drying loft, stretched on hooks, and left till dry. They now form a white, tough, brittle leather; but the glossy finish and softness of kid is imparted by a dressing, composed of 20 pounds of the finest wheat flour, and the yolks of eight dozen eggs.[1] This paste, diluted with water, is put into a drum, and the skins are made to rotate therein, when they so completely imbibe the egg-liquor, that scarcely anything more than water remains. This dressing is generally repeated before the skins are hung up to dry. But the softness and elasticity yet remain to be given. The skins are dipped into pure water, and allowed to remain for a few minutes; they are then spread out, and worked upon a board, and *staked* upon the *stretching* or *softening* iron. This is an iron plate, rounded over at the edge, mounted upon an upright beam, and fixed to a heavy plank, well secured in the floor. By these

(1) This egg-dressing is indispensable in the preparation of white lamb and kid-leather. The eggs used for the purpose are imported from France and Flanders; and at the time of the writer's visit to Messrs. Bevington's factory at Bermondsey, they had a stock of 60,000 eggs pickled in salt.

processes the skins are considerably extended in length, and all hard points and roughnesses removed. They are finally smoothed with a hot iron, and are then ready for the glover.

Dressing in Oil, consists in first soaking the skin in water, and then, by continued hard rubbing, forcing oil or grease into its pores. As the water evaporates, the oily matter combines in some way with the fibres of the skin; renders it permanently soft, and by keeping out the water prevents it from decay.

A process of this kind was formerly applied to the skin of the Chamois goat, and hence arose the term *chamois*, *shammy*, or *shamoyed*, as applied to the leather itself, and *shamoying* to the process. As this is the only kind of leather which, when dyed, will bear washing without the colour being materially injured, it is also called *wash*-leather.

Wash-leather is prepared, in this country, from doe's or sheep's-skin: and for the inferior kinds, the flesh side of sheep's-skin, as obtained from the split hide, is employed; the other half, or grain side, being tawed for skiver-leather. Indeed, it is common always to get rid of the *grain* before a skin is shamoyed; because, by doing so, the extensibility and softness of the skin are much increased. The grain is removed by an operation called *frizing;* that is, one end of the skin is wrapped over a pole, the grain side uppermost, and then the whole surface is scraped with a round knife, or with pumice-stone.

The grain being removed, the skins are placed in bran liquor, and then wrung out; they are afterwards spread upon a table, sprinkled slightly with oil, and folded up in balls of four each, and beaten by a number of heavy wooden hammers in the *fulling stocks.* The heads of the hammers are covered with copper, and they work in a kind of trough, in which the skins are placed. After having been beaten for two or three hours, according to their texture and the state of the weather, they are taken out, exposed to the air, oiled and fulled several times, until all appearance of greasiness has disappeared. They are next hung up in a warm room, when a kind of fermentation takes place, which opens the pores of the skin and promotes the combination of the oil. They are next scraped with a blunt concave knife, and scoured in a weak warm potash lye, in order to get rid of the uncombined oil. Having been washed in water, they are gently dried, smoothed, and made supple by the stretcher iron, or by passing them between rollers.

Section VII.—Statistics of Leather.

In the year 1830, the duty on leather was wholly repealed; so that there are now no means of ascertaining the quantity produced in any one year. The yearly production, on an average of three years, ending in 1822, was 48,244,026 pounds. In this year the duty was diminished from 3*d.* to 1½*d.* per pound; and the average production of the next three years showed an increase of 30 per cent. The repeal of the duty and the increase in population have, doubtless, increased the consumption of leather to a far greater extent. It has been calculated that the annual production of all sorts of leather, tanned, tawed, dressed, and curried in Great Britain is about 60,000,000 pounds; the value of which, taking one quality with another, at 1*s.* 6*d.* per pound, amounts to 4,500,000*l.* It is supposed that the value of the leather forms only one-third of the finished articles, so that the ultimate value of the manufacture, in Great Britain alone, must be 13,500,000*l.* Some estimates are even higher than this, and make the aggregate value of leather goods to exceed 18,000,000*l.* per annum. "Nor will this amount appear excessive," says Mr. M'Culloch, "if we consider that there is only a very small proportion of the people, however poor they may be, who do not wear leather shoes or boots; that the use of leather gloves is general among all but the labouring classes; and that the harness of horses used for pleasure, as well as those used for agricultural and other business operations, is made with this material, besides an endless variety of things in daily use, which will suggest themselves to every one's mind." Taking the population of Great Britain at 21,000,000, and supposing that each individual spends on an average 8*s.* per annum for shoes and boots only, the annual outlay for these articles will be 8,400,000*l.* Some have supposed that the value of saddlery, harness, gloves, &c., is, at least, equal to that of shoes; but this estimate is probably too high.

In consequence of the odours diffused by tan-yards, they are generally situated at the outskirts of a town. During a long period, Bermondsey was the principal seat of the leather manufacture in England, on account of the Thames tide-streams affording an abundant supply of water. Although the Bermondsey manufactories are more extensive than ever, tan-yards are established near most of the towns of this country.

LEMON—Salts of. This term is incorrectly applied to the binoxalate of potash, or *salt of sorrel*, as it is called in commerce. Large quantities of it are prepared in Switzerland and the neighbouring countries from wood sorrel. About 60 or 70 lbs. of the plant, when in full vegetation, yield about 5 oz. of the crystallized salt. This salt is sometimes used instead of lemons in making lemonade and flavouring punch, and hence the term *essential salt of lemons.* The oxalic acid contained in it ought to forbid such a use. This salt unites readily with several of the earths and with most of the metals, and hence is used in removing ink-spots and iron-moulds from linen, one proportional of its acid uniting with the iron, forming a *soluble* and colourless oxalate of iron.

LENS, a term originally applied to a magnifying-glass, from *lentile*, a bean or seed, the shape of which is somewhat convex on both sides. Opticians now distinguish six kinds of lenses, three convex and three concave. The three convex are, 1, *plano-convex*, plane on one surface and convex on the other: 2, *double convex*, or convex on both surfaces: when the radii are equal, the lens is termed *equi-convex;* when one radius is six times the other, it is called a *crossed* lens: 3, *Meniscus*, or convex on one side and concave on the other, the convexity being greater than the

concavity. All these lenses are thicker in the middle than at the edges. The concave lenses are, 4, *plano-concave,* or plane on one surface and concave on the other; 5, *double concave,* or concave on both surfaces; 6, *concavo-convex,* or more concave on one side than convex on the other. All these lenses are thinner at the middle than at the edges. The last-named lens

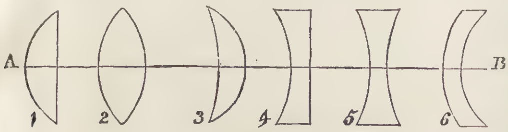


Fig. 1297.

of either kind is also called *periscopic,* from σκοπέω, to see, περὶ, round about, from their giving a larger field of view than ordinary spectacles. This advantage is of doubtful character, since the spherical aberration of such lenses exceeds that of other lenses.

The optical properties of lenses will be noticed under Light. In the present article we propose to enter into a few particulars respecting the grinding and polishing of lenses, referring to the article Casting and Founding, for the methods of casting, grinding, and polishing the specula used for reflecting telescopes.

When two hard bodies are rubbed or ground together there is always a tendency for one of them to become convex and the other concave, and it is by taking advantage of this tendency that glass is ground into lenses. It can be proved by certain optical properties of a well-formed lens, that no part of its surface deviates by a ten-millionth of an inch from a truly spherical figure: indeed, surfaces cannot be made so accurately *plane* as they can be made convex.

In the grinding of lenses counterpart tools of metal are used, adjusted to the curvatures of the lenses, and serving as a medium for applying the grinding and polishing powders. Each tool consists of a convex and a concave surface, which are first ground together into shape and thus made to correct each other's defects. In preparing one of these tools a convex and a concave template is first made to the radius of the required curve. If the radius be large the templates are cut out of crown glass by cementing a sheet of that material upon a bench, and mounting a glazier's diamond upon the end of a light radius bar: a brad-awl being stuck into the bench serves to support the other end, the distance from the diamond to the awl being the radius of the curve. The glass, being cut by the diamond, is broken in the line of the cut, by which means concave and convex edges are formed: these edges are ground by being rubbed together with a little emery and water with the pieces in a flat position, one of them being occasionally turned over in order to verify the curves. Templates are more usually formed of sheet brass; those of large radii being cut with a strong radius-bar and cutter; whilst those of a few inches radii are cut in the turning-lathe.

The tool used in making convex lenses is a concave *shell* of cast-iron, shown in section Fig. 1298. The wooden pattern used in casting this shell is carefully turned to the curve of the template, while a similar shell, turned to a radius of about $\frac{3}{8}$th inch larger than the template, is used as a foundation for the polisher. A

Fig. 1298.

Fig. 1299.

convex tool, or *runner* of cast-iron, Fig. 1299, of about $\frac{1}{2}$-inch less radius than the template, is used as the support for common glasses, a number of which are ground together. A pair of brass tools, Fig. 1300, of the exact curvature of the templates, are also prepared and made to fit each other with great nicety. The concave half is used for correcting the curvature of the lenses after they have been roughly shaped in the concave shell, Fig. 1298.

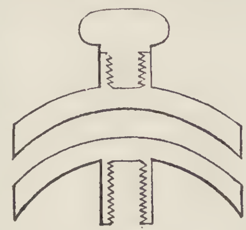


Fig. 1300.

The convex half is used for preserving the true shape of the concave grinding tool and polisher. The screws at the back of these tools admit of their being fitted to the lathe mandrel, to be turned to the curvature of the templates. These screws also serve to secure the tools to the top of an upright post or pedestal, about 3 feet high, firmly fixed into the floor, and furnished at the top with an iron block and a vertical screw. The brass tools having been turned to the proper curve, the convex tool is fixed by its screw to the top of the post; a wooden handle is screwed into the back of the concave tool, and they are then ground together with emery and water, or with dry emery distributed as uniformly as possible by rubbing it level with a piece of glass of similar curvature, wiping off any excess from the margin of the tool. The operator works the concave upon the convex tool with a circular swinging stroke, and between every few strokes he moves a little way round the post, the object being to bring the two surfaces in contact in every possible position, and to rub them upon each other at all angles, so as to produce a true spherical figure.

The glass for the lenses is brought into a circular form by means of *shanks* or flat pliers of soft iron, which do not slip as steel would do. The iron jaws being applied near the edges of the glass cause it to crumble away in fragments, and by this *shanking* or *nibbling* the glasses are made circular, but they are left somewhat larger in diameter than is required for the finished lenses. A small quantity of cement is then poured upon each glass; and when this has set, more is added, until it rises in a hemispherical mass capacious enough to be grasped with the fingers.[1] Each glass is next rough-ground within the shell, Fig. 1298, with river sand and water, or coarse emery

(1) The cement is formed by mixing with 14 parts of melted pitch about 4 parts of sifted wood ashes, the latter serving to reduce the adhesiveness of the pitch. If the cement be too hard and brittle, it may be softened with tallow or hogs' lard.

and water, until the surfaces are brought nearly to the curve of the shell. The shell is placed within a shallow tray, for the purpose of catching the loose sand or emery thrown off in the grinding. The glasses are rubbed with large circular strokes, and when this rough grinding is completed on one side the glass is warmed to detach the handle of cement, which, being attached to the ground side, the other side is similarly ground. By leaving the edge of equal thickness all round, the two surfaces are kept tolerably parallel.

All lenses are rough-ground in this way: those of the best quality are next ground into the correct shape in the brass tool, and polished one at a time. For common lenses several are operated on together. As many as four dozen common spectacle-glasses are sometimes cemented upon a runner and ground and polished together; but they must be arranged symmetrically round a central lens, as 7, 13, or 21; or a group of 4 may form the nucleus, in which case the numbers are 4, 14, 30. Lenses of medium quality and size are often ground true and polished 7 at a time. Taking the last case, the method is as follows:—The cement at the back of the lenses is flattened with a hot iron, and the 7 lenses are placed with the cemented sides upwards in the concave brass tool, one lens in the centre and the other six at equal distances around. The iron runner is then heated and carefully placed upon the backs of the lenses; the cement softens and adheres firmly to the iron, which is then cooled with a wet sponge, matters being so arranged that the spaces between the lenses are nearly filled up with the cement, but the cement must not be quite level with the surface of the lenses. The block of lenses thus formed, Fig. 1299, is screwed into the post and ground with the concave brass tool, Fig. 1300, six sizes of washed emery being used in succession, each finer than the one previously used, the last size being the fine powder collected after one hour's subsidence, and which produces so smooth a surface as to appear partly like a polish. The grinding is continued with each size of emery until all the marks produced by the previous size have been removed, the whole apparatus being carefully washed after each application, so as entirely to get rid of one emery before a finer one is used. The *trueing* of the lenses, as it is called, being completed, the polishing is next proceeded with. The polisher is made by warming an iron shell; coating it uniformly with about $\frac{1}{4}$-inch thick of melted cement, and then pressing down upon the cement, by means of the brass convex tool, a piece of thick woollen cloth with the nap worn off, or seared off with a hot iron. Putty power[1] is then sifted uniformly over the cloth, moistened by sprinkling water over it, and worked into the cloth with the brass concave tool. Fresh powder is added, and the working continued until the surface is quite level. For small lenses a polisher of kerseymere is used: this is more readily filled up with the putty powder than the coarse woollen cloth. The polisher is placed upon the block of lenses, fixed on the post, and worked with wide and narrow elliptical strokes, the operator continually moving round the post. The putty powder must not be so wet as to run loose upon the polisher, nor so dry as to be cut up by the edges of the lenses. It must be wet enough to take a partially glazed appearance from the action of polishing, and when entirely glazed a little water must be sprinkled over it. The pressure must be very moderate.

The next process is to grind the edges of the lenses circular, and in order that the axes of the lenses may coincide with the axis of the tube of the telescope or other instrument in which they are to be mounted, the lenses are cemented upon a chuck in the lathe, and before the cement has set the lathe is made to revolve, and the reflection of a candle or any fixed object watched, and the lens adjusted, until the image appears to be quite stationary notwithstanding the motion of the lens: the axis of the lens and that of the mandrel of the lathe are then known to coincide, and the edge is ground circular with a piece of brass supplied with emery and water, placed beneath the lens, and gradually raised by a screw.

Concave lenses are ground and polished in the same manner as the convex, only they are fixed in the concave tools and ground upon the convex, which is always the lower tool, when several glasses are worked together.

In the Transactions of the Society of Arts, vol. xlix., Mr. C. Varley has described a lathe for grinding and polishing lenses and specula. In this arrangement, the lower tools are not mounted upon a fixed post, but upon a vertical revolving axis. By this means the process is considerably expedited, but the results are less accurate than by the plan already described. In the 50th vol. of the same Transactions, Dr. R. Greene's machine for grinding and polishing specula and lenses is also described.

Common lenses, which are produced in large quantities in manufactories, are also ground and polished by machinery. "The block of lenses is mounted upon a slowly revolving axis, placed vertically, and the upper tool has an eccentric motion, given to it by means of a small crank, fixed on the lower end of a second vertical axis, placed a little on one side of the central line of the lower axis. A pin fixed in the centre of the back of the upper grinding tool, enters a socket in the crank, and the revolution of the latter causes the upper tool to describe small circles, which, combined with the slow revolution of the block of

(1) The putty powder used by Mr. A. Ross, the optician, is prepared as follows:—Metallic tin is dissolved in nitro-muriatic acid, and precipitated from the filtered solution by liquid ammonia, both being largely diluted with water. The peroxide of tin is washed with plenty of water, collected on a cloth filter, and squeezed as dry as possible in new linen cloth: the mass is next pressed in a screw-press as dry as possible. The lump thus produced is broken up, dried in the air, and finely levigated on a plate of glass with an iron spatula, and exposed in a crucible to a low white heat. Before being heated the powder has but little cutting properties, but being made anhydrous by heat the particles assume the form of lamellar crystals, and act with far more energy, yet without scratching, than any of the ordinary polishing powders. The coarser particles are separated by washing over. A little crocus is added by way of colouring matter, which makes it easier to ascertain the quantity of powder remaining on the polishing tool.

lenses, causes every point of the grinder to describe epicycloids upon the surface of the lenses, much the same as in the circular strokes employed in grinding lenses by hand. The radius of the crank admits of adjustment, to give various degrees of eccentricity to the upper tool, and the pressure is regulated either by a spring, or by adjusting the weight of the grinder."

The best lenses for object glasses of telescopes, are ground and polished singly by hand. They are polished with putty powder upon thick lutestring silk cut to the width of about $\frac{7}{8}$ths the diameter of the lens: this is stretched across the middle of the brass tool, and the lens is rubbed backwards and forwards in straight lines along the silk, the lens being continually twisted round in the hand.

In making the object glasses of achromatic telescopes, it is of importance to be able to measure accurately the radii of curvature of the lenses, which are first tried experimentally, and then made as nearly as possible to the radii obtained by calculation, so as to correct the chromatic and spherical aberration. In the Transactions of the Society of Arts, vol. liii., Mr. A. Ross has described an instrument called a *sphereometer*, for measuring the curvature of the grinding tools.[1]

Small microscopic lenses, varying from $\frac{1}{4}$ to $\frac{1}{20}$th of an inch in diameter, are also ground and polished singly, the radius of curvature being too small to allow of a number being grouped together. "The templates are made as small discs of steel with slender stems turned in the lathe. For lenses, the radii of whose curvature are 5, 10, or 20 hundredths of an inch, the diameters of the discs are 10, 20, or 40 hundredths. They are made with square edges, and when hardened, are applied diametrically, as the finishing tools for turning the small metal cups or concave grinding tools. For measuring the diameters of the discs they are applied either in the sector gauge, or one of the sliding gauges often used for measuring the diameter of wire, and graduated decimally for reading the width of the opening to the $\frac{1}{100}$th or $\frac{1}{1000}$th of an inch. The cups, when turned, are charged with emery, and put in rapid revolution in the lathe, which, for these minute lenses, is in general very small, and worked with the drill bow. The lens is cemented with shell-lac, upon a small wooden stick, and held against the grinding tool with a continual change of angle, the end of the stick being moved in the arc of a circle, while it is, at the same time, twisted on its axis." The grinding is performed with the same succession of emeries as is used for the larger lenses. The polishing is done with bees'-wax hardened with fine crocus, of such a consistence as to assume the form of the lens with moderate pressure, and hard enough to retain the figure during the polishing. The brass cups used in the polishing are turned in the lathe of a little larger radius than the grinding tool, and the surface is roughened for holding the wax, which is poured into the heated tool, and when cold, moulded into shape with a convex tool, or turned in the lathe first, with a thin scraping tool, and then with a circular disc, as in the case of the grinding tool. In polishing the lens, the wax is kept wet with fine crocus and water applied with a feather. The lenses are separated from the runner or handle by warming them, so as to soften the shell-lac; and the last particles of cement are washed off by means of spirits of wine.

Lenses for spectacles are formed out of Brazilian pebbles of transparent, colourless quartz. The stone is cut into slices by the lapidary, then snipped into the form of the lenses, and ground and polished by the methods above described.

In fitting lenses into the tubes of optical instruments, the brass cells or rings are turned with a slight excess of metal projecting,

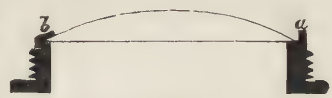


Fig. 1301.

as at *a*, Fig. 1301: the glass being put into its place, this thin edge is then curled over the glass as at *b* by means of a burnisher applied while the ring is revolving in the lathe.

LEPIDOLITE, also called *lilac*, or *lithia mica*, occurs massive, and is generally composed of small thin flexible scales, translucent and sometimes hexagonal. Its fracture is uneven; its colour pearl grey, peach-blossom, rose and purple, red and greenish. Sp. gr. 2·85. It is found in granite, near Rosena, in Moravia, at Perm in Russia, at the Isle of Uton in Sweden, and in North America. The red variety from Moravia yielded to Dr. Turner, silica 50·35, alumina 28·30, potash 9·04, lithia 4·49, oxide of manganese 1·23, fluoric acid and water, 5·20.

LEUCITE is found in lava, in trapezoidal crystals and massive. The primary form is a cube: the fracture conchoidal, undulating, shining. Hardness 5·5 to 6. Colour yellowish, greyish, or reddish white. Streak white. Lustre, vitreous. Sp. gr. 2·483. The massive variety is amorphous and granular: reduced to powder it renders vegetable blues green. A specimen from Albano, analysed by Arfwedson, yielded silica 56·10, alumina 23·10, potash 21·15, oxide of iron 0·95.

LEVEL, an instrument for finding a line or surface exactly level, or such as shall be everywhere parallel to the true horizon, or at right angles to the plumb-line, or direction of gravity. It also enables the surveyor to find the difference between the heights of two or more places on the surface of the earth, as in the operation of LEVELLING.

For the attainment of these objects, various instruments have been contrived, the action of most of which depends on gravitation. The *plumb-level*, described under BRICKLAYING, is constructed in various forms, and under different names; but the principle is the same in all, viz. to attach a thread and plummet to the upper part of a board, or flat frame of wood or metal, so that, when the thread, hanging freely, coin-

(1) This instrument is also figured and described in the third vol. of Holtzapffel's Mechanical Manipulation, to which Mr. Ross contributed much of the valuable and interesting information respecting the manufacture of lenses. Gill's Technical Repository also contains some interesting details on the subject.

cides with a fiducial line marked on the frame, it is at right angles to the base of the instrument, and the surface to which the base is applied must be level; but if the thread declines from the mark, the surface is lower on one side than on the other. In nice operations, the vibrations of the lead are troublesome: but these may to a great extent be prevented by immersing the lead in a vessel containing water or other liquid; or the plummet may be enclosed in a glass cover, to protect it from the wind; and sights, and a telescope may be added, applying it upon or parallel to the base, when it is required to take the level of distant objects. The *Artillery Foot-level*, Fig. 1302, consists of two legs or branches of equal lengths, and at their juncture is a small hole, from which hangs a thread and plummet, playing on a quadrant, which is divided on each side into 45° from the middle. When the ends of the two branches are placed on a surface, and the thread hangs perpendicularly over the middle division, the plane must be level. By placing the two ends on a piece of artillery, the latter can be raised to any proposed angle as indicated by the plummet. The *Gunner's level*, for levelling cannons and mortars, is a triangular brass plate, Fig. 1303, about four inches high, at the bottom of which is an arc, graduated into 45°; on the centre from which the arc was struck a piece of brass A B turns, and may be fixed by a screw: the lower end B serves for a plummet and index to show the various degrees of elevation of pieces of artillery. The instrument has a brass foot to set upon cannons or mortars, so that when they are horizontal, the instrument is perpendicular. The foot is placed on the piece to be elevated, so that the point of the plummet may fall on the proper degree: this is called *levelling the piece*. The *Balance-level* is suspended as a pendulum: it is furnished with sights, which, when the instrument hangs at rest, show the line of level: a telescope may be used to assist the observation. There are various forms of this level, which has not much sensibility, and is very liable to be disturbed by wind. *Mariotte's Reflecting level* is a long surface of water, made so as to reflect to the eye an inverted image of the object; and the point where the two objects appear to meet is on a level with the place where the surface of the water is found. A reflecting level by Cassini is a steel mirror, placed a little before the object glass of a telescope suspended perpendicularly. The

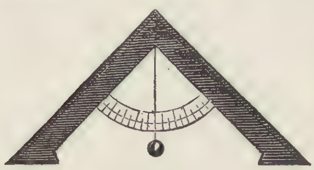


Fig. 1302

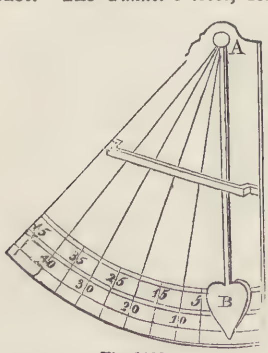


Fig. 1303.

mirror makes an angle of 45° with the telescope when the perpendicular line of the telescope is converted into a horizontal line, which is identical with the line of level. The *water-level* shows the horizontal line by means of a surface of water in a trough; or it may be made with two cups fitted to the two ends of a pipe, 3 or 4 feet long, and about 1 inch in diameter. Water is poured into the cups, so as to fill the tube and part of the cups: the pipe is movable on its stand by means of a ball-and-socket joint, and it will be evident that the surface of the liquid in the two cups will always be in the line of level. A glass cylinder, 3 or 4 inches long, is sometimes attached to each end of the pipe instead of a cup, and a coloured liquid, water or mercury, being poured into the pipe, rises into the cylinders, and thus determines the line of level. This form of instrument is convenient for levelling at small distances. The *air-level* marks the line of level by means of a bubble of air enclosed with a liquid in a glass tube curved slightly upwards, the two ends of the tube being hermetically sealed. The tube is commonly secured in a brass bed or case, with an opening in the middle through which the bubble of air may be observed, and this brass bed is fixed to a brass or other plane, which being placed on any given surface, if the bubble rests at a certain mark in the middle of the tube such surface is level; if not level the bubble will rise towards one end. An instrument of this kind, with sights, is shown in Fig. 1304. The air-level L L′ is about 8 inches long, and 7 or 8 lines in diameter: it is set in a brass bed *t t′* with an opening in the middle L L. The bed is attached to a straight ruler about 12 inches long, and at each end is a sight, *s s′*, exactly perpendicular to the tube, and of equal height. Each sight has a square hole subdivided by a cross of thin brass, in the middle of which is a very small hole, through which a point on a level with the instrument is to be observed. The brass bed is attached to the ruler by means of screws, one of which, *a*, serves to raise or depress the tube so as to bring it to a level. The top of the ball and socket is fastened to a small ruler, one end of which is fastened with a screw to the large ruler, and at the other end is a screw *b* for slightly raising and depressing the instrument when nearly level.

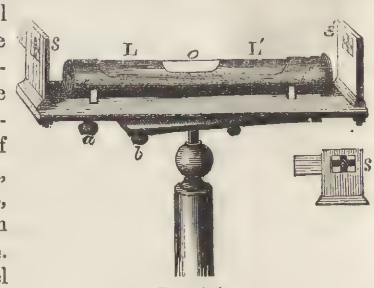


Fig. 1304.

The *spirit level* is the most accurate levelling instrument: it was invented by Sisson, and greatly improved by Ramsden, Troughton, and Gravatt. It consists essentially of a glass tube nearly filled with spirits of wine, and hermetically sealed at both ends, so that when held with its axis in a horizontal position the bubble of air is in contact with the

upper surface. If the tube be perfectly cylindrical, the exact horizontality of its surface may be ascertained by the extremities of the air-bubble being at equal distances from the middle point in the length of the glass.

At first view nothing would appear more simple than the construction of such a tube. There are, however, numerous difficulties and sources of error which have been investigated by Mr. Nixon of Leeds, whose papers on this subject in the *Philosophical Magazine* for 1827, 1829, and 1831 will repay a careful perusal. The following remarks on the theory and construction of spirit levels are abridged from an article on the subject contained in the *Encyclopædia Britannica.*

When a plummet or a pendulum vibrates freely in a circular arc, the tendency of gravity to bring it to the resting position is everywhere as the sine of the angular distance from that position. Now if the bubble in the spirit-level move in a circle, it is obviously acted on by a force precisely similar to that which gravity exerts upon the plummet; and therefore it would seem that a spirit-level should measure small angles with the same accuracy as a sector whose radius is equal to that of the curvature of the glass tube, or a plumb-line of the same length; but there are some causes which diminish its accuracy. When the bubble of air has been brought to the middle of the glass tube, and when the tube, after being deranged, is restored to the very same position, we cannot be sure that the bubble of air will return to the very middle of the tube. This irregularity is produced by the friction of the included liquid against the sides of the tube, and depends on the magnitude of the bubble and the quantity of liquid. In a good level, where the bubble moves about five lines for a minute of inclination, this uncertainty does not exceed half a line, which may be ascertained by pointing the telescope to any object. The coincidence of a plumb-lime with a particular mark will, on account of the insensible oscillation of the thread, leave about double the uncertainty which is left by the index of a sector, and which may be estimated at about a hundredth of a line. Levels are commonly made of glass tubes in the state in which they are obtained from the glass-house. Of these, the straightest and most regular are selected and examined, by filling them nearly with spirit of wine, and ascertaining by trial that side at which the bubble moves most regularly, by equal inclinations of the instrument upon a stage called the *bubble-trier*, which is provided with a micrometer screw for that purpose. The most regular side is chosen for the upper part of the instrument, the others being of little consequence to its perfection. Spirit of wine is used, because if pure it does not freeze at natural temperatures, and is more fluid than water. Sometimes, indeed, though very rarely, ether is employed. The tube and the bubble must be of considerable length. The longer the bubble, the more sensible it is to a small inclination. A very small bubble is scarcely sensible; it appears as if attached to the glass, and moves but slowly. In the use of a level of this kind constructed by Langlois, it was remarked, that when it was properly set in the cool of the morning, it was no longer correct in the middle of the day, or when the weather became hot; and that when it was again rectified for the middle of the day, it became false in the evening, after the heat had diminished. The bubble was much longer in cold than in hot weather, and when longest it was too much so, and could not be kept in the middle of the tube, but stood a little on the one or the other side, though the inclination was precisely the same. These defects were small, and such as claim the notice of careful observers only; but they appeared of too much consequence not to produce a wish to remedy them. It was observed that they arose from inequalities in the interior surface of the tube; and by examining a great number of tubes, selected for levels of the same kind, there was reason to conclude that all these levels would have more or less of the same defects, because there was not a tube of a regular figure within. They were at best no otherwise cylindrical than plates of glass can be said to be plane before they are ground. The irregularities were easily discernible. It was therefore concluded that it would be advisable to grind the inner surfaces of the tubes, and give them a regular cylindrical, or rather spindle form, of which the two opposite sides should correspond with portions of circles of very long radius. To accomplish this, a rod of iron was taken of twice the length of the glass tube, and on the middle of this rod was fixed a stout tube of brass of the same length as the tube of glass and nearly filling the bore. The rod was fixed between the centres of a lathe, and the glass gently rubbed on the brass cylinder, with fine emery and water, causing it to move through its whole length. The glass was held by the middle, that it might be equally ground, and was from time to time shifted on its axis, as was also the brass cylinder, in order that the wear might be everywhere alike. The operation had scarcely commenced before the tube broke; and several others experienced the same misfortune, though they had been well annealed. It was supposed that the emery which became fixed in the brass might contribute to split the glass, each grain continuing its impression with the same point, in a straight line, and in some instances might be disposed to cut the glass as a diamond would do. Yet it is curious that some artists find a wooden cylinder to suit pretty well, probably because it does not hold the emery so firmly as brass does. But when a cylinder of glass was substituted instead of the brass, the emery, rolling on the surface of the glass, instead of fixing itself, had better success; so that the tube and cylinder touched each other through their whole length. The same operation was continued, using finer and finer emery to smooth the tube, and prepare it for polishing; after which the tube and cylinder having been well washed, thin paper was pasted round the cylinder, and very equally covered with a small quantity of Venice tripoli. The tube was then replaced and rubbed as before, till it had acquired a polish.

A level thus ground may be either of the proper sensibility, or be too much or too little sensible. It will be too sluggish, if, before grinding, exclusive of the inequalities of the tube, its diameter in the middle of the length should much exceed the diameter of the extremities; or it will be too sensible if this diameter should not sufficiently exceed the other; or, lastly, if the middle diameter be smaller than that of the extremes, the bubble will be incapable of continuing in the middle, but will, in every case, either run to one or the other end, or be divided into two parts.

To correct these defects, and to give the instrument the required degree of perfection, it is proper to examine its figure before the grinding is entirely finished. For this purpose, after cleaning it well, a sufficient quantity of spirit of wine must be put into it, and secured by a cork at each end. The tube must then be placed on the forks or Y's of a bubble trier, and its sensibility, or the magnitude and regularity of the space run over by the bubble, by equal changes of the micrometer screw, must be ascertained. If the runs or spaces passed over be too great, they may be rendered smaller by grinding the tube on a short cylinder; but if they be too short they may, on the contrary, be enlarged, by grinding on a longer cylinder. It is necessary, therefore, to be provided with a number of these cylinders of the same diameter, but of different lengths, which it is advisable to bring to a first figure, by grinding them in a hollow half cylinder of brass. By means of these it will be easy to regulate the tube of the level to any required degree of sensibility, after which the tube may be very quickly smoothed and polished.

A level thus ground was one foot in length, and so was the cylinder on which it was first worked. When finished it was found to be too sensible. It was therefore worked on another cylinder between nine and ten inches long, which diminished its sensibility so far, that the bubble, which was 9 inches and 4 lines long, at the temperature of 68° Fahr, was carried from the middle of the tube exactly one line for every second of inclination. This sensibility was thought sufficient; but if greater is required, it may be obtained by the process here described.

It may be remarked, that a glass tube is very subject to be split by grinding its inner surface; the same tube will not be endangered by grinding its external surface, even with coarse emery; and when once the polish of the inside is ground off, the danger is over, and coarser emery may be used with safety. Thick glass is more subject to this misfortune than thinner. The coarsest emery used in grinding the tube here spoken of was sufficiently fine to employ one minute in descending three inches in water.

Spirit levels are known by various names. The *Y level* is so called from the supports in which the telescope rests, resembling in shape the letter Y: this is the oldest construction of the spirit level now in use. *Troughton's improved level* is a more perfect and stable instrument than the former. This has been modified by Mr. Gravatt in what is called the *Dumpy level*, represented in Fig. 1305. Its optical advantages consist in adapting to the telescope an object glass of large aperture and short focal length, for the purpose of obtaining the light and power of a large instrument, without the inconvenience of its

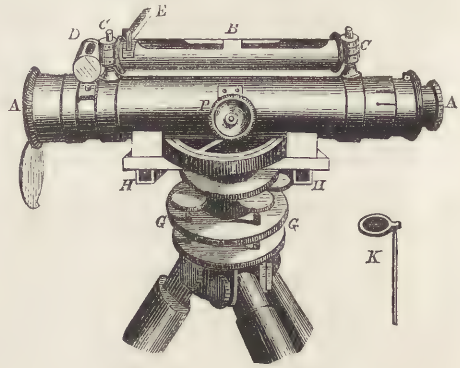


Fig. 1305. GRAVATT'S LEVEL.

length. A A is the telescope with a diaphragm and cross wires: the internal tube or slide which carries the eye-piece, &c. is nearly equal in length to the external or telescope tube, which being sprung at its aperture secures to the slide and eye-piece a steady and parallel motion when adjusting for distinct vision of a distant object by the milled head P. B, is the spirit level attached to two rings passing round the telescope, bythe capstan headed screws C C, which are the means of adjusting the air bubble of the level for parallelism with the line of collimation. D is a small spirit level placed across the telescope at right angles to the principal level C C: it is of use in setting the instrument up approximately level by means of the legs only, which saves time and also the wear of the parallel plate screws. Having directed the sight to the staff and adjusted for distinct vision, the two levels at once show which of the screws require touching to perfect the level before noting the observation. A mirror mounted by a hinge-joint on a spring piece of brass, is placed on the telescope at E: its use is to reflect the image of one end of the air bubble in the principal level to the eye, so that the observer, having carefully adjusted his level, can while reading the staff see that the instrument retains its position, by noticing if the reflected end of the air bubble coincide with the proper division of the small scale fixed on the bubble tube. The parallel plates and screws are shown at G G. It is convenient for one of the screws to rest in a notch or Y fixed on the lower plate exactly over one of the legs, so that by giving motion to that leg only after the other two are fixed in the ground, the instrument can be set up so nearly level that a very small motion of the parallel plate-screws will be required to perfect it. H H are two capstan screws, which are used for making the spirit bubble maintain a central position in its tube while the instrument is turned completely round on the staff-head. I is the compass, which contains either a floating card or graduated silver ring mounted on the needle, the divisions of which

are magnified by a lens K, which slides in a socket, not shown in the figure, affording the means of reading to 10 minutes of a degree; the rapid vibrations of the card or needle are checked and speedily brought to rest by a contrivance, in which a spiral spring is moved by a milled-headed screw; this also serves to clamp the needle when not in use.

The wire plate or diaphragm in the above instrument is usually furnished with three threads, two of them vertical, between which the station-staff may be seen, and the third by which the observation is made is placed horizontally, (see Fig. 1307;) or a pearl micrometer scale may be fixed perpendicularly on the diaphragm instead of wires. This consists of a fine slip of pearl with straight edges, one of which is divided into a number of parts, generally hundredths or two-hundredths of an inch, and is so fixed that the divided edge intersects the *line of collimation*,[1] the central division indicating the point upon the staff where the observed level falls.

Before the instrument is used in the ground, it requires certain corrections. Mr. Gravatt's instructions are as follows:—Let three pickets be driven into the ground, in a line, and at equal distances from one another, and let the spirit level be set up successively in the middle between the first and second and between the second and third pickets: then, by means of the screws, having adjusted the spirit tube so that the bubble of air may retain the same place while the telescope is turned round on the vertical axis, direct the object end of the telescope successively to the station-staves held up on the different pickets, read the several heights, and take the differences between those on the first and second and on the second and third staff. Now, the staves being at equal distances from the instrument, it is obvious that any error in the line of collimation, or from the spirit tube not being parallel to that line, will be destroyed, and the differences between the readings on the staves are the differences in the levels of the heads of the pickets; but unless the instruments are perfect, this will not be the case if the instrument be set up at any point which is unequally distant from all the pickets; therefore, from such point direct the telescope to the staves, and take the differences of the readings as before. On comparing these differences with the former, a want of agreement will prove that the intersection of the wires is not in the optical axis, and the error may be corrected by means of the parallel plate screws. After the agreement has been obtained, should the bubble of air not stand in the middle of the tube, it may be brought to that position by a screw at one extremity of the case, and the instrument is then completely adjusted.

For further particulars on this subject we must refer to Mr. Simms's Treatise on Mathematical Instruments.

LEVELLING is the art of determining the heights or depressions of points on the ground, with respect to a spherical or spheroidal surface, such as the earth, or when the extent of ground is inconsiderable, with respect to a horizontal plane passing through some given point on the ground. In extensive operations of this kind undertaken by the astronomer, the figure of the earth must be taken into account; but when the object is to determine the profile of the ground, for a canal or a railroad, it is sufficient to consider the surface to which the points are referred, as that of a sphere. The civil engineer, therefore, interprets the word levelling rather as the difference between two planes or heights than the attainment of a perfectly horizontal surface: and his object in the operation is generally to ascertain how much ground must be elevated or removed to assist the flow of water, or the construction of a road over valleys or mountains. What is called a *true* level follows the circumference of the earth; an *apparent* level regards the earth as a plane surface, and is, in fact, a tangent to the earth. In levelling through long distances, an allowance is made for the curvature of the earth, for which purpose accurate tables have been completed for all distances within the range of an observation. Allowance is also made for refraction, which varies from $\frac{1}{4}$th to $\frac{1}{24}$th of the angle subtended by the horizontal distance of objects. In the ordinary state of the atmosphere, the refraction is about $\frac{1}{14}$th of the horizontal angle, and the radius of the curvature of the ray 7 times that of the earth. The effect of refraction may be allowed for by computing the correction for curvature, and taking $\frac{1}{7}$th for the quantity by which the object is rendered higher by the refraction than it ought to be. Tables have been prepared for making the necessary corrections for refraction.

The staff or target used for determining the height of the several objects above or below the level line, is shown in Fig. 1306. It is usually a rod $1\frac{1}{2}$ inch square and $6\frac{1}{2}$ feet long; it is made of mahogany, and inlaid on its face with a white wood, to receive the graduation marks and figures. It is formed of two pieces dovetailed into each other throughout their whole length, so that one half of the rod slides upon the other, so as, when drawn out, to form a length of 12 feet, and yet leave a foot of the two halves united, to preserve the straight line of the instrument. The divisions are reckoned from the bottom of the staff. The vane is a thin piece of mahogany, 10 inches long and 3 wide, with projections behind, which form a socket for fitting the rod, and allowing it to slide up and down. There is a flat spring in the socket for making the motion more precise. The centre of the vane has a hole, through which may be read off the figure on the staff, and the edge of this hole being chamfered, the horizontal wires of the telescope which cross it can be distinctly perceived as they lie over the divisions of the scale beneath. Fig. 1306 shows a portion of

Fig. 1306.

(1) The line which joins the centres of all the lenses, such as A B, Fig. 1297.

the staff *g e* brought within the vertical wires *c d* of the telescope: *a b* represents the horizontal wire. When the staff is placed in a vertical position, the vane is elevated or depressed by the person holding it, according to certain signals given by the engineer at the levelling instrument, until the vane is made to coincide exactly with the horizontal wire. When the cross wire of the vane is raised so high as to intersect 6 feet, there is a stop to prevent its being pushed higher; when a greater height is required, the vane is put to this height, and is raised by sliding up the front portion of the staff, which carries the vane with it. The rods are graduated in different ways. Some have a double scale of divisions running up the middle of the front; some are graduated into feet and inches divided into tenths; others into feet divided into hundredths. The calculations are more easy when the levels are taken in inches and tenths, or in feet and hundredths.[1]

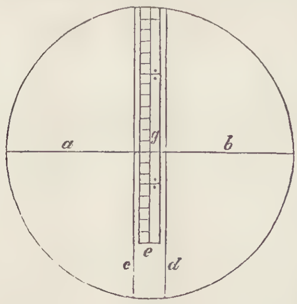


Fig. 1307.

Mr. Gravatt's scales, Fig. 1308, now in common use, have no vanes; their graduations are marked in feet, tenths, and hundredths: they are made of three pieces of mahogany, with joints at the ends for uniting them in one length of 17 feet or more. Such staves can be packed up with the stand of the instrument. Mr. Sopwith has added a spring catch to the sliding part; but care is required lest when the face is turned from the last forward station to become the next back, an error of $\frac{1}{8}$th inch result from placing it carelessly on the ground.

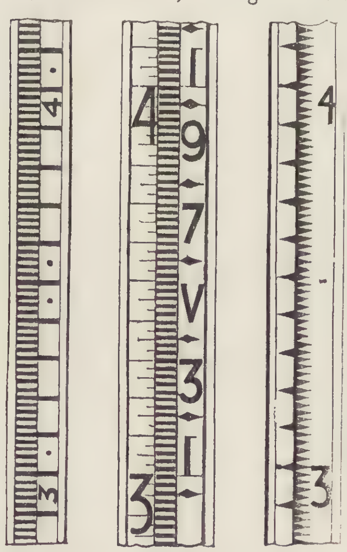


Fig. 1308.

The most simple and usual method of levelling is as follows:—Convenient stations A, B, &c. Fig. 1309, having been selected on the line of operation, the distances between them are determined either by actual admeasurement, or by computations founded on the data afforded by a previous survey of the ground. The spirit level is then set up at or near the middle of the interval between every two such points in succession. When the telescope thus placed, as at *a*, has been made horizontal, an assistant

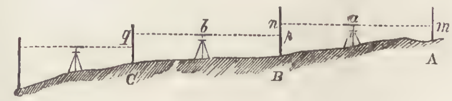


Fig. 1309.

at each of the stations A and B, holding a station-staff in a vertical position, moves the vane along the staff upwards or downwards, according to the directions of the observer at the telescope, till it appears to coincide with the intersection of the two wires of the telescope, which coincides with the optical axis or line of collimation. The points thus determined on the staves are represented by *m* and *n*, which are evidently *level points*, or points equally distant from the centre of the earth. Therefore, the heights A *m* and B *n* being read on the graduated staves, the difference between them will give the relative heights of the ground at A and B; that point of course being the highest at which the distance of the vane from the ground is the least. A similar process is repeated with respect to the points B and C, the instrument being placed at *b* midway between them, and the operation is to be continued to the end of the line on which the profile is required. It is usual to insert in a book the heights B *n*, C *g*, &c. in a column headed *Fore sights*, and the heights A *m*, B *p*, &c. in a column by the side of the former headed *Back sights*. The difference between the sums of the numbers in these two columns is equal to the height of one extremity of the line above the other.

Suppose, for example, it were required to find the difference of level between the points A and G, Fig. 1310: a staff is set up at A, the instrument at B, and another staff at C at the same distance from B that B is from A. The readings of the two staves are then

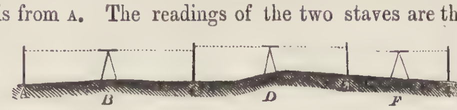


Fig. 1310.

noted; the horizontal lines connecting the staves with the instrument represent the visual ray or line of sight. The instrument is then conveyed to D, and the staff which stood at A is now removed to E, the staff C retaining its former position, and from being the forward staff at the last observation, it is now the back staff; the readings of the two staves are again noted, and the instrument removed to F, and the staff C to the point G; the staff at E retaining the same position, now becomes in its turn the back staff, and so on to the end of the work, which may thus be extended many miles. The difference of any of the two readings will show the difference of level between the places of the back and forward staff; and the difference between the sum of the back sights and the

(1) Fig. 1307 represents the appearance of the wires and staff as seen through an inverting telescope. The horizontal cross wire coincides with the division ·20 above 16 feet, the staff being read downwards in consequence of its apparent inversion: the reading therefore of such an observation to be entered in the field book would be 16·20 feet.

sums of the forward sights will give the difference of level between the extreme points: thus,—

	Back Sights. ft.	dec.	Fore Sights. ft.	dec.
A and C . . .	10	46	11	20
C „ E . . .	11	33	8	00
F „ G . . .	7	42	7	91
Sums . .	29	21	27	11
	27	11		
Difference of level	2	10,		

showing that the point G is 2 feet and $\frac{10}{100}$ths higher than the point A.

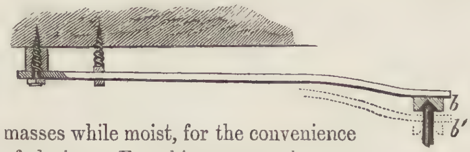
In order to enable the engineer to determine the depths of his excavations or the heights of his embankments, the profile of the ground is laid down on paper in portions of convenient length. A right line is drawn to represent one parallel to the horizon, and it passes through the highest or lowest point of the natural ground: the heights or depressions of the remarkable points, as A B, &c. with respect to such line, are obtained by additions or subtractions from the numbers in the field-book, and are by a proper scale set out from that line, or others drawn perpendicularly to it, at intervals equal to the horizontal distances between the same points. On joining the series of points thus obtained, the figure of the required vertical section of the ground is obtained. If it be merely required to ascertain the difference of level between two places, it is not necessary to level in a straight line between the two places; and, indeed, the presence of woods and water may prevent such a method: a circuitous route is in such cases adopted.

The reader who desires further information on this subject, is referred to the works which we have consulted in preparing this and the previous article, viz. Mr. Simms's Treatises on Levelling, 2d edition, 1843; on Drawing Instruments, 1845; and on Mathematical Instruments, 1836. Also the articles Levelling and Spirit Level, in the Penny Cyclopædia.

LEVER, see MECHANICS.

LEVIGATION is the process by which substances are reduced to a state of minute division by rubbing them between two hard surfaces when formed into a paste with water. It is distinguished from TRITURATION, in which the comminution is effected without the aid of a liquid. The porphyry slab and muller used in trituration is also used in levigation; but in Germany a shallow porcelain vessel is employed. In the process of levigation an amount of pressure is required beyond that which the weight of the pestle would usually produce. This is effected by means of a wooden spring, Fig. 1311, fixed to the ceiling, to the free end of which is attached a square block of wood b, with a conical hole in the centre, in which the pointed end of the handle or shaft of the pestle works. The pestle is represented standing in a levigating vessel, and the shaft of the pestle admits of being lengthened or shortened by means of the long rod, and the binding screws s s. The dotted lines b' show the position of the spring in its free state, before applying the pressure, which is of course regulated by adjusting the length of the rod by means of the screws.

Substances which have been finely divided by levigation are in some cases formed into small conical masses while moist, for the convenience of drying. For this purpose they are placed in a small hollow metallic cone c, Fig. 1312, fixed in a circular wooden frame f, which is furnished with a support l, and a handle h. The levigated and still moist substance being put into the cone with a knife, the mould is inverted over a chalk stone, or other absorbing surface, and the leg l slightly tapped until the conical mass falls out. The nodules thus prepared are afterwards dried by exposure to a current of air. In this way the conical nodules of levigated chalk, bole, and other substances are prepared.[1]



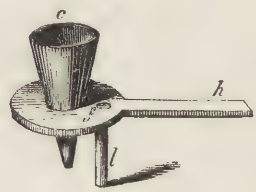


Fig. 1312.

Fig. 1311.

LEWIS. A simple but ingenious apparatus used by masons in hoisting large blocks of stone. Its invention is commonly ascribed to a French mechanic employed on the works of Louis the Fourteenth: the name given to the machine was therefore in compliment to that monarch. It appears, however, from an examination of ancient ruins that an apparatus answering similar purposes was in use long before the age of Louis le Grand. Whitby Abbey, originally founded in 658, and rebuilt as a church in the reign of William Rufus, long formed one of the most beautiful ruins of this country. In 1762, during a violent storm, it fell to the ground, yet so excellent was the cement used in its construction that the pillars and arches remained prostrate in nearly their original forms. Some of these stones, especially the key-stones of the arches, the largest of which weigh nearly a ton and a half each, present a cavity in the crown, similar to those cut into large blocks of stone, for the purpose of raising them by the lewis.

The modern form of the lewis is shown in Fig. 1313, in which a and b are two pieces of iron in the form of inverted wedges. These pieces are inserted into a quadrangular hole made in the stone: the two opposite and shortest sides of the

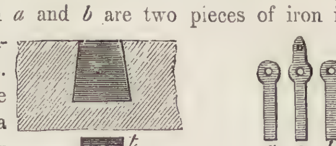


Fig. 1313.

(1) See Mohr & Redwood's Practical Pharmacy, London, 1849.

hole are dove-tailed, as shown in the figure, which represents a vertical section of the hole, t being the plan of the hole at top, and o the plan of the hole at bottom. The dimensions are 5 inches long at the top and 6 inches at bottom: the width 1 inch and the depth 7 inches. The width is sometimes $1\frac{1}{2}$ inch and the depth 4 or 5 inches. The pieces a b being first introduced into the hole, c is driven in and a bolt b' b'', Fig. 1314, is passed through the holes: r is the ring of the lewis on which the tackle is hooked; each end of this is likewise perforated to receive the bolt, which enters at b' and forelocks at b''.

Mr. Gibson, who first discovered tokens of the use of the lewis in Whitby Abbey, remarks that the

Fig. 1314.

Fig. 1315.

machine used at that period must have been of a somewhat different form and considerably less powerful than that now employed; yet he estimates its strength to have been equal to the raising of a block of four tons, which is larger than any stones found in ancient buildings. Fig. 1315 represents the supposed form of the lewis used at the erection of Whitby Abbey. In forming the cavity, the point a was left apparently as a guide to point the two principal members d e of the machine to their destined places, where they were secured by a third part b perforated at the head to receive, in conjunction with c d e f, the forelock bolt.

LICHENS. Cellular flowerless plants, spreading over rocks, trees, or even dry bare earth, and having in most instances a dry crustaceous nature, or a fleshy substance variously coloured. In some cases lichens appear as grey or yellow stains, adding much to the picturesque effect of old buildings; in others they hang in mossy luxuriance from the branches and trunks of trees; in others again they cover the earth itself, springing up to a larger growth than their fellows. These, in arctic regions, afford important winter pasturage to rein-deer, the species commonly called *rein-deer moss* being a luxuriant growth of a lichen (*Cenomyce rangiferina*).

Lichens do not exist on decaying vegetable matter, this office being filled by the fungi. These are transient in their nature, whereas lichens are perennial, and grow on the bark of living vegetables, as well as on stones, &c. The finest species are met with near the equator, but lichens are to be found in all parts of the world, even to the limits of eternal snow. Many of the species afford dyes, but the best known are those which yield cudbear, and archil, well-known dyes, described under ARCHIL. Some of the lichens possess nutritive properties, depending upon the presence of an amylaceous substance analogous to gelatine. In the lichen called Iceland Moss (*Cetraria islandica*), Berzelius found 80·8 per cent. of pure starch, or amylaceous fibre. Several of these gelatinous lichens, called *Tripe de roche*, and forming various species of *Gyrophora*, afford subsistence to the Canadian hunters in cases of emergency.

LIFE-BOAT. In our article BOAT the principle of the life-boat is stated, and examples are given of some approved forms. But the numerous cases of shipwreck which have recently taken place, and especially the lamentable accident which occurred to a South Shields life-boat a few years ago, whereby 20 pilots were drowned, have led to an act of munificence on the part of the Duke of Northumberland, President of the National Shipwreck Institution, which has already produced most important results, and which calls for further notice. With a view to stimulate invention, the President offered a reward for the best model of a life-boat. This offer was responded to by boat-builders and others from many parts of this kingdom, as well as from France, Holland, Germany, and America, so that 280 models and plans were sent in. About fifty of the best of these formed the Duke's contribution to the Great Exhibition. With a generosity worthy of the sacred cause, his Grace has likewise publicly expressed his intention of placing the best life-boats that can be built, and every means for saving life from shipwreck, on all the exposed points of the coast of Northumberland. He has also caused to be prepared at his own expense a Report, accompanied by plans and drawings of the most approved forms of life-boat, 1,300 copies of which have been gratuitously distributed, not only through this kingdom, but in all the maritime nations of Europe and the United States of America. From this work we have been permitted to copy the illustrations which accompany this article.

No greater service could perhaps be rendered than the spreading abroad in this manner, and as widely as possible, the knowledge necessary for effective action. A remarkable degree of supineness has hitherto prevailed on this important subject, and of the life-boats at present stationed on our shores, we regret to say, one half are deemed unserviceable. A most interesting *Wreck Chart* for 1850, which appears in the Report of the Northumberland Life-boat Committee, shows the existing life-boat stations on the coasts of Great Britain, and also marks the number of wrecks which took place in that year. It appears that 681 British and foreign vessels were wrecked on the coasts and within the seas of the British isles, during the year, and that of these 367 were total wrecks, sunk by leaks, or collisions, or abandoned, and 304 were stranded and damaged so as to make it necessary to discharge the cargo. About 780 lives were

lost. These numbers, large as they appear, are not unusual, but fairly represent the nature of our annual loss. A single gale of wind often strews our coasts with wrecks, and causes wide-spread sorrow and bereavement. In two days, viz. the 25th and 26th of September, 1851, 117 vessels were wrecked within our seas, during the gale which then prevailed; and during the month of January of the present year, 120 vessels have shared the same fate. These numbers, fearful as they are, may perhaps fall considerably below the real amount, for no complete and accurate record of shipwrecks is kept. To meet this appalling amount of damage we have on the coast of England eighty life-boats, in Scotland eight, and in Ireland eight, making ninety-six in all, only one half of which are really effective.

These facts sufficiently prove the necessity for more active exertion in endeavouring to save life on our shores, and the value of the steps taken by the Duke of Northumberland. Baron Dupin, in his capacity as chairman of the jury, under which the life-boat models were found, declared them to be among the most valuable productions in the Great Exhibition; and remarked that these, taken in connexion with the facts stated, furnished "a splendid example of liberality in the cause of humanity and practical science, never surpassed, if ever equalled." The Northumberland Prize-model—for which the sum of one hundred guineas was given to Mr. James Beeching of Great Yarmouth, represents a boat that will pull and sail well in all weathers, and whose excellency for the purposes required has been proved at Ramsgate, where a boat built after the model is now stationed, and acts admirably. This boat has a moderately small internal capacity under the level of the thwarts for holding water, and ample means for freeing herself readily of any water that might be shipped; she is ballasted by means of water admitted into a well or tank at the bottom after she is afloat, and by means of that ballast, and raised air-cases at the extremities, she would right herself in the event of being upset. At an able Lecture on Naval Architecture, delivered by Captain Washington, R.N., before the Society of Arts, March 3, 1852, being one of the series in illustration of the benefits of the Great Exhibition, the subject of life-boats was fully entered on, and a model of the above life-boat was placed on the table, and described. Captain Washington also favourably noticed many other life-boats, of which models were sent to the Great Exhibition; and expressed satisfaction at the number sent by men who are earning their daily bread as working shipwrights or boat-builders in the various private and public dockyards of the kingdom. He also enumerated the essential points as to form, dimensions, internal fittings, &c. necessary to be considered in the construction of a life-boat. Of this part of his subject, as contained in the copy of his lecture distributed to the members of the Society of Arts, we give the following abridged account:—

Form.—In *form*, the life-boat should resemble the whale-boat, that is, both ends alike, but with more breadth of beam; fine lines to enable the boat to pull well, but sufficient fulness forward to give buoyancy for launching through a surf; good sheer of gunwale, say an inch for each foot of length, but rounded off towards the extremes; a long flat floor; sides straight in the fore-and-aft direction; the gunwale strake in the midships to tumble home slightly to protect the thole-pins, and the bow strake to flare out slightly to throw the sea off; as much camber or curvature of keel as can be combined with steady steering, and safe launching from a beach, in order that the boat may be turned quickly to meet a heavy roller when about to break on her broadside.

Dimensions.—As to *length*, life-boats may be generally classed as from 20 to 25 feet, from 25 to 30, or from 30 to 36, the last being the maximum. The smaller size is convenient in parts of the coast where it is difficult to find a crew; as being more easy of transport on shore, and more readily manned and launched. Such a boat, with six men, will generally bring on shore the whole of the crew of a stranded vessel. Two boats, one of only 18 feet length, the other 24 feet, built by Plenty, of Newbury, have been the means of saving 120 lives within the last few years. Where a sufficient crew can be found, a boat of 30 feet length, to pull ten oars double-banked, is probably the best adapted for a life-boat. Such are the boats at Liverpool, Dundee, and other large ports. One of these is said to have brought ashore at Liverpool on a special occasion, 60 persons. The maximum boat of 36 feet is used at Yarmouth, Lowestoft, Deal, &c. where it is the invariable custom to go off under sail, and where there is never a difficulty in finding beachmen to launch or man the boats, of whatever size. Some boats of extraordinary size, which may be considered exceptions to the general rule, are also in use at the above places. These are from 40 to 45 feet long, admirably manned and handled, and have been the means of saving about 300 lives within the last 30 years. With respect to breadth of beam, in a rapid tideway, as the Tay, the Humber, the Bristol Channel, &c. a boat, somewhat of the galley form, but with ends like a whale-boat, would be more suitable than a wider boat. In these exceptional cases the breadth of beam might be one-fourth the length; but for a life-boat, where the requirements are roominess for passengers, width to pull double-banked, stability to resist people moving about, and occasionally pressing down on one side in rescuing a man from the water, it should never be *less* than one-fourth. As to depth, a boat that has to be launched through the surf on a beach should not be too shallow in the waist. As a general rule the free-board or height of gunwale, from the surface of the water, with crew and gear on board, should not be less than from 22 to 24 inches. The weight suitable to a life-boat does not appear to have been much attended to, but Captain Washington gives, as a fair general rule, 1 cwt. or $1\frac{1}{4}$ cwt. for each foot of length. The weight of gear would vary from 5 cwt. to 15 cwt. according as it comprises oars, masts, sails, anchor, cable, warps, &c. Whatever the length of the boat, the space between the thwarts should not be less than

from 28 to 30 inches, or the loom of one man's oar is liable to strike the back of the man abaft him. The oars should be short to pull double-banked, and of fir. They should pull with iron thole-pins, having rope grummets secured to them, and the pins should be so placed that the boat may be pulled either way by the man merely turning round on the thwarts.

Materials.—About one-tenth of the models sent to the Exhibition were of iron, but Captain Washington does not advocate the adoption of metal for life-boats, and supposing them to be introduced he thinks copper preferable to iron. Wood has been the material hitherto employed, and of this, well-seasoned Scotch larch is the best, its specific gravity being little more than double that of cork. Neither Polish nor Italian larch should be trusted to. Gutta-percha, caoutchouc, and other materials have been proposed, but their merits have not been sufficiently tested. Combinations of these with cork, or with layers of thin wood, seem well adapted for air-cases.

Extra Buoyancy. — This is the characteristic feature of a life-boat, therefore its nature, amount, and distribution require close attention. If sufficient buoyancy can be attained by cork, it is far preferable to air-cases, as not being liable to accident. A portion of cork may be used under the flat or floor of the boat, so as to reduce the internal capacity, and enable the boat to free herself of water. Cork varies in weight and in price. The common sort used by fishermen as floats only weighs about 12 lbs. per cubic foot, and costs about 12*s.* per cwt. A heavier sort weighs 15 lbs. per cubic foot. These might be advantageously disposed in the bottom of the boat, covered with gutta-percha, or a light casing to keep the water out of it, and the boat might then bid defiance of accidents, as thus armed,—even if bilged against a rock, she would float. With respect to air-cases, those which have been built into the boat can scarcely be depended upon for a year. On inquiry there is reason to believe that there does not exist a complete air or water-tight case (undetached) in any life-boat that has been six months in use around the coasts of Great Britain. Detached air-cases may be better, but all require extreme caution. Metal air-cases are supposed to offer security, but in a life-boat laid open at Woolwich several holes were found half an inch in diameter in the copper tubes previously supposed to be air-tight. Copper like other metals is all the more liable to corrode when placed in conjunction with sea-water. Teasdel, an experienced life-boat builder at Great Yarmouth, makes his detached air-cases of thin boards of willow wood covered with painted canvass. The cubical contents of the air-cases in a great part of the models sent to the Exhibition measured from 200 to 300 feet, equivalent to the support of from six to nine tons of dead weight. This amount is unnecessary, to balance the extra weight likely to be put into a life-boat. In a 30 feet boat, provided with ample delivering valves, 100 cubic feet, or the equivalent of three tons, is sufficient extra buoyancy for all general purposes.

The distribution of this extra buoyancy requires great care: except under special circumstances it should be placed high up in the boat, so as not to affect her stability. In order to reduce the internal capacity of the boat, that she may rise under the weight of a heavy sea that may fall on board, and to enable the delivering valves to act freely, a certain amount of space should be occupied under the flat or floor of the boat, so as to exclude the water; and the question is, so to fill this space with a material of less specific gravity than water, yet sufficiently heavy to ensure the boat's stability when the flat or flooring is laid at from 10 to 12 inches above the keelson, or about the water-line of intended immersion; thus acting generally as ballast, but on emergency as extra buoyancy. From the various plans adopted this would seem the most difficult problem to solve in the whole arrangements of a life-boat. In some cases a tight deck is placed fore and aft at from 16 to 18 inches, and even 24 inches above the keelson, with only air beneath; the result is, that the weights in the boat raise her centre of gravity, and there is a risk of her upsetting when a sea is shipped. In other cases, to avoid this danger, an iron keel is added, or a well or tank is inserted amidships for water ballast, which, as long as it remains in place, restores the equilibrium. Water ballast has the advantage of being taken in only when the boat is afloat, and thus leaving her light for transport on shore; but the use of cork under the deck, as above described, is considered preferable by Captain Washington. The next point in the distribution of extra buoyancy, is the placing of a requisite amount of air-vessels in the head and stern sheets of the boat from the floor up to the gunwale height, in order to give self-righting power, always taking care to leave access to within three and a half or four feet of the stem and stern post, to enable a man to stand there and receive people from the wreck, as it commonly occurs that a boat cannot go alongside a stranded vessel, but has to receive the rescued men either over the head or stern of the boat. Air-cases should also be placed along the sides of the boat fore and aft, chiefly to diminish the internal capacity. They should be detached and have valves inserted in them, by which they can be aired and preserved better. Well's disc valve is recommended. The more the internal capacity can be reduced consistently with leaving space for the rescued crew the better the life-boat. If possible, the capacity for holding water up to the level of the thwarts of a boat 30 feet long should not exceed three tons. It may be diminished by side air-cases from the thwarts to the floor, or by air-cases under the thwarts.

Means of Freeing the Boat of Water.—Every life-boat should be provided with the means of freeing herself of water as rapidly as possible. Yet in some of the models no provision is made beyond a bucket for baling. The provision required consists of efficient tubes and scuppers, closed by self-acting valves. A boat can free herself most rapidly by tubes through the bottom, but as these are liable to be choked in the possible case of a boat grounding, it

is better also to have scuppers in the sides. The area of the tubes should not be less than one square inch for each cubic foot of capacity; more would be better.

Provision for Self-righting.—The property of self-righting, when recently proposed as one of the requisites of a good life-boat, was almost treated with contempt by some of our best boat-builders, yet it was this property which was publicly acknowledged and exhibited at Leith in 1800 by Mr. Bremner, whose boat is figured at page 148, vol. i., under our article Boat. Since his time the provision for self-righting has been neglected, and the consequence has been that instances have occurred of life-boats when upset remaining bottom upward, to the destruction of the poor creatures beneath. This proves the necessity of grappling with the difficulty, if such it be, and of overcoming it. "Most life-boats have good sheer of gunwale, and consequently raised extremities, in which air-cases should be placed, in order that when the boat is bottom upwards, their buoyancy may co-operate effectually with the weights in the bottom of the boat (now raised, it may be, considerably out of the water) to restore her to her originally upright position. The higher the centre of gravity of a vessel or boat is above the centre of buoyancy, *cæteris paribus*, the less is her stability; and by the separation of these two centres, a condition of instability will ensue, the effect of which will be, that with the slightest motion the boat will reverse her position, or right herself. To determine the necessary extent of separation of those centres in each case involves careful calculation. The best mode of applying this principle will readily occur to most boat-builders. The objections to the raised air-cases at each end are the wind they hold in pulling off a lee-shore, and the obstacle to approaching the stem and stern of the boat; the latter may be modified, the former must be tolerated for the greater benefit in another respect that arises from their adoption. If air-cases be used in the extremes, a layer of cork on the top will afford great protection to them, and better footing for the crew when necessity requires them to stand or jump on them."

Ballast.—The advantages of water-ballast have already been stated. It is necessarily used in connexion with so-called water-tight cases, and therefore requires very good workmanship in the bulkheads or partitions of the well, in order that they may not become leaky by straining when at sea, or by shrinking when the boat stands ashore, which she sometimes does for a year together. A doubt may arise, too, whether a boat does not require her ballast as much, or more, at the time of launching than at any other time; lightness has its advantages, but in launching through a surf, a boat requires a certain weight, so as not to be readily thrown aside by a breaking sea. After all, the ballast supplied by cork seems the best adapted to meet the varied contingencies to which a life-boat is subject. Also a moderate sized cork fender, about four inches in diameter, should be carried round the sides and both ends of the boat, at about six inches under the gunwale. Holes in the bilge pieces, to enable a man to lay hold of them, should the boat be upset; timber heads to make warps fast to at each bow and quarter; long sweep oars for steering at each end; a stout roller in the stem and stern-post to receive the cable; spare oars, one for each two that the boat pulls; life-belts, life-buoys, and life lines; hand-rockets, heaving-lines, and such minor fittings, are indispensable in every life-boat.

Transporting Carriage.—The carriage for transporting a life-boat along shore, or when the tide is out, for carrying it down to the water, and launching it without risk, should combine lightness with strength to carry at least 40 cwt. in case of need. The boat should be supported as near the ground as may be, so as not to strike the bottom in going over a rocky beach. The wheels should be of large diameter, with broad tires to prevent their sinking in the sand. Of the models sent to the Exhibition, not one exactly fulfilled the conditions which seem essential. But a carriage is now in the course of construction at the Royal Arsenal at Woolwich, which it is hoped will prove to be well adapted to its purpose.

The essentials of a life-boat thus gathered from the statements of an experienced naval officer, will prepare the reader to understand the merits of two life-boats, of which figures are given—the one being the prize-boat which gained the premium offered by the Duke of Northumberland, and which was decidedly the best of the competing models with reference to the points already laid down; the second being a more recent boat, in which, after a careful study, the good points of all the competing boats representing the essential features of a good life-boat, have been combined and exemplified.

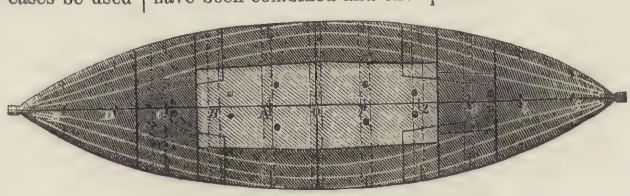


Fig. 1316. Plan of the Northumberland Prize Boat.

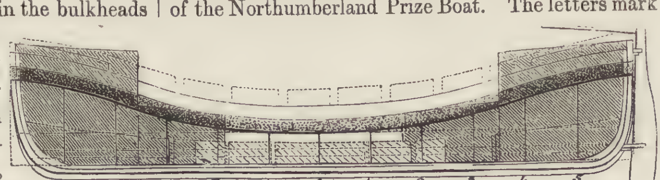


Fig. 1317. Northumberland Prize Boat.—*Sheer Plan.*

Figs. 1316 and 1317 are the plan and sheer plan of the Northumberland Prize Boat. The letters mark the fore-part of the boat, the figures the aft. The dark parts of Fig. 1316 represent *air*, the light part, *water*. The dark band in Fig. 1317 represents *cork*, the other tints *air* and *water*. The body of this

boat is of the form usually given to a whale-boat—a slightly rounded floor, sides round in the fore and aft direction, upright stem and stern post, clench-built, of wainscot oak, and iron-fastened. Length extreme 36 ft., of keel 31 ft., breadth of beam $9\frac{1}{2}$ ft., depth $3\frac{1}{2}$ ft., sheer of gunwale 36 in., rake of stem and stern-post 5 in., straight keel 8 in. deep. The boat has 7 thwarts 27 in. apart, 7 in. below the gunwale, and 18 in. above the floor; pulls 12 oars, double-banked, with pins and grummets. A cork fender, 6 in. wide by 8 in. deep, runs round outside at 7 in. below the gunwale. Extra buoyancy is given by air-cases 20 in. high in the bottom of the boat, under the flat; round part of the sides, 24 in. wide by 18 in. deep, up to the level of the thwarts, leaving 10 ft. free amidships; and in the head and stern sheets, for a length of $8\frac{1}{2}$ ft., to the height of the gunwale; the whole divided into compartments and built into the boat, also by the cork fenders. Effective extra buoyancy 300 cubic ft., equal to $8\frac{1}{4}$ tons. For ballast a water-tank, divided into compartments, placed in the bottom amidships, 14 ft. long by 5 ft. wide, and 15 in. high, containing 77 cubic ft., equal to $2\frac{1}{4}$ tons when full, and an iron keel of 10 cwt. Internal capacity of boat under the level of the thwarts 176 cubic ft., equal to 5 tons. Means of freeing the boat of water, tubes through the bottom, 8 of 6 in. diameter, and 4 of 4 in. diameter—total area, 276 square in., which is to the capacity in the proportion of 276 to 176, or as 1 to 64. Provision for righting the boat if upset, $2\frac{1}{4}$ tons of water-ballast, an iron keel, and raised air-cases in the head and stern sheets. Rig, lug foresail and mizen; to be steered by a rudder; no timber heads for securing a warp to. Draft of water with 30 persons on board, 26 in. Weight of boat, 50 cwt., of gear, 17 cwt.—total, 67 cwt. Would carry 70 persons; cost, with gear, 250*l*.

Figs. 1318 and 1319 represent a boat which is supposed to combine the good points of all the others. It is the work of Mr. James Peake, Assistant Master

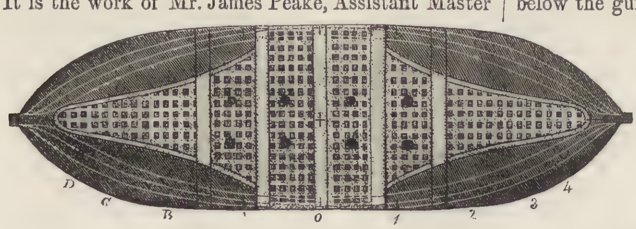


Fig. 1318. PLAN OF PEAKE'S LIFE-BOAT.

Shipwright in Her Majesty's Dockyard, Woolwich. The form of this boat is that usually given to a whale-boat, having a long flat floor amidships, sides straight

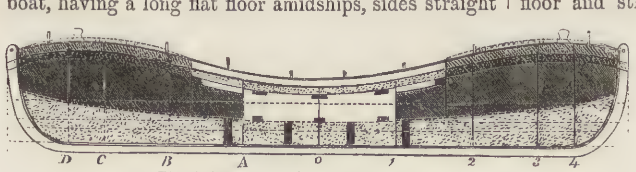


Fig 1319. PEAKE'S LIFE-BOAT.—*Sheer Plan.*

in a fore-and-aft direction, raking stem and stern-post, diagonally built of two thicknesses of rock elm, and copper-fastened. Length extreme, 30 ft., length of keel 24 ft., breadth of beam $8\frac{3}{4}$ ft., depth $3\frac{1}{2}$ ft., rake of stem and stern-post $6\frac{1}{2}$ in. in a foot; straight keel 4 in. deep, and bilge-pieces with openings in them to lay hold of, on each side on the bottom. The boat has 5 thwarts, 7 in. wide, 28 in. apart, 7 in. below the gunwale, and 15 in. above the floors, pulls 10 oars, double-banked, with pins and grummets. A fender of cork, 4 in. wide by $2\frac{1}{2}$ in. deep, extends fore and aft at 4 in. below the gunwale. Extra buoyancy is obtained by cork (shown by the light tint in Fig. 1319), placed the whole length of the boat, under the flooring, to a height of 12 in. above the keelson, and by light cork or detached air-cases in the head and stern sheets up to gunwale height. Effective extra buoyancy 105 cubic ft. equal to 3 tons. A light water-tight deck will be placed on the cork to protect it, and above that a light grating. For ballast, the weight of the cork in the bottom, and an iron keel of 5 cwt. Internal capacity for holding water up to the level of the thwarts, 140 cubic feet, equivalent to 4 tons. The means of freeing the boat of water are by 8 tubes of 6 in. diameter through the bottom, and 6 scuppers through the sides at the height of the flooring, giving a total delivering area of 300 square inches, which is to capacity as 1 to 5. The provision made for righting the boat consists in the sheer given to the gunwales, raised air-vessels or cork in the head and stern sheets, and the ballast arising from the weight of cork in the bottom, and the small iron keel. A passage 18 in. wide, up to within 2 ft. of the stem and stern is left between the raised air-cases in the extremes, and the top of the cases is protected by a layer of cork. Rig, fore and mizen lug sail. To be steered by a sweep oar at either end. Timber heads for warps are placed at each bow and quarter, and a roller for the cable in the stem and stern-post head. A locker under the flooring amidships for the anchor and cable to be secured down to the keelson, and covered with a water-tight scuttle. A life-line fore and aft at a foot below the gunwale, and short knotted life-lines to be hung over the side at each thwart. Draft of water with 30 men on board, 16 in. Weight of boat and fittings, 38 cwt. Would carry 60 persons. Actual cost, as built in one of H. M's. dockyards—materials, 40*l*.; labour, 45*l*.: total, 85*l*.

It is anticipated that this boat, from her form, will pull fast in all weathers, and be fully able to contend against a head sea. She would sail well, and from her flat and long floor and straight sides, would have great stability, and prove a good sea-boat. A boat of this form could not be readily upset, but should this occur, the sheer of gunwale, raised air-cases in the extremities, weight of cork in the bottom, and iron keel, would cause her to right herself. The boat would readily free herself of water, and if the ample delivering-tubes became choked, there are sufficient scuppers at the sides. The builder only offers this

as a selection from the best points of other boats, but it appears better adapted for the purpose than any other. One of these boats is to be placed at Cullercoats, on the coast of Northumberland, two miles north of the entrance of the Tyne—a station well adapted for testing its capabilities.

We cannot leave this subject without expressing both regret and shame, that the cause of seamen excites so little interest among the inhabitants of our sea-girt isle. It is reckoned that a thousand British lives are lost annually from shipwreck, and the greater part on our own shores; yet hitherto only a few feeble efforts have been made to lend a helping hand to those whose business is on the great waters, and to provide them with the means of rescue in their distress. Our markets and our tables are richly supplied with fish, and it would appear a hardship if it were not so; but how little thought is bestowed upon the men whose perilous calling furnishes these luxuries. How coolly are shipwrecks and their results spoken of, as a matter of course, in stormy weather! Surely this apathy has greatly arisen from ignorance that anything could be done to lessen the evil. Surely it is not generally known that there is such a Society as the National Shipwreck Institution,[1] with a President at its head, whose unexampled generosity puts us all to shame. That Society, undeterred by its very small means, is endeavouring to increase the number of life-boats, and other means of help on every coast, and to stimulate exertion by rewards honorary and pecuniary. It also spreads abroad, as far as it can, the knowledge of what is necessary to be done in cases of emergency, calling attention to the neglected state of some existing life-boats, and putting on record the brave deeds of those who risk their own lives to save their fellow-creatures. Such a Society ought to be supported as a matter of duty by every Englishman who has the means. How know we, but that, for want of the life-boat which this Society desires to place on every exposed part of our island, our own lives or those of our friends may be sacrificed? Like Southey's "Sir Ralph the Rover," who mourned too late the destruction of the Inchcape bell, which warned him from the fatal rock, we may yet have to mourn the neglect which deprived us of the means of rescue from shipwreck. A recent publication of the National Shipwreck Institution, issued monthly, under the title of the "Life-Boat," (price three-halfpence,) gives a list of shipwrecks every month, with many interesting particulars connected with the subject.

LIGHT. It was formerly supposed that light was an emanation of material particles from luminous bodies; but in our own day, philosophers incline to the opinion that it is produced by the undulations in, or vibrations of, an elastic ether. It is not necessary to refer to either hypothesis in explaining a few of the elementary effects to which a ray of light is subject under various circumstances. It is evident that some substance or action, which we call *light*, travels from every visible point to the eye in straight lines, radiating in all possible directions from every visible point of matter, whether emitting light from its own resources, or dispensing what it receives from some foreign source. By calculations based upon the eclipses of the four satellites or moons which revolve round the planet Jupiter, astronomers have ascertained that light travels at the rate of 192,000 miles in a second. By another phenomenon, called the *aberration* of light, this fact has been confirmed, together with the additional one, that light, from various celestial sources, travels with the same speed. This aberration is common to *all* the heavenly bodies, causing them all to appear a little out of their true place, and it forms one of those corrections which must be applied to every celestial observation. It arises from an application of the principle advocated by the sportsman, of "shooting *before* the hare." As the observer is moving along with the earth, at the same time that the light is travelling to him, it follows that, if he point his telescope exactly towards any celestial object, he will not see it, because the light which enters the telescope will, before it can reach his eye, be struck by the side of the tube; unless, indeed, he be travelling exactly *towards* or *from* the object, in which case there is no aberration. In other cases, the telescope must evidently be pointed a little to one side of the object in order to see it, so that almost every star is seen out of its place. Now, the amount of this displacement being ascertained, is found in all cases, whatever be the object seen, to be exactly such as may be calculated from the known velocity and direction of the earth's motion, taking the velocity of light always at the same rate, viz. 192,000 miles a second. The earth's motion being very slow compared with this (barely a 10,000th so fast), the amount of the aberration is very small, never exceeding 20½″, or about half the apparent diameter of Jupiter.

The motion of light, under ordinary circumstances, in *straight lines only*, is probably the first physical fact that we learn, and that on which we found every inference depending on the evidence of vision. It is to some exception to this law that every variety of ocular illusion or deception is referable; for when the rays coming from any object suffer any bending before arriving at the eye, the object is seen out of its true direction, viz. in that direction which is *last* assumed by the rays immediately before entering the eye.

Light not only proceeds ordinarily in straight lines, but such lines or rays emanate from every point of a visible object, and proceed in every direction. Any number of rays of light can cross each other in the same point of space without jostling. If a small hole be made from one room into another through a thin screen, any number of candles in one room will shine through this hole, and illuminate as many spots in the other room as there are candles in this, all their rays crossing in the same hole, without hindrance or dimi-

(1) The office of the Royal National Shipwreck Institution, is at 20, John Street, Adelphi *President.*—The Duke of Northumberland. *Secretary.*—Mr. Richard Lewis, to whom letters should be addressed

nution of intensity, just as sounds of different character proceed through the air, and speak to the ear, each in its own peculiar language, without materially interfering with each other.

Owing to the rectilinear motion of light, the *pencil*, as it is called, which emanates from any point diminishes according to the law of inverse squares [See HEAT, Fig. 1135], and the apparent superficial size or area of any object diminishes as its distance from us increases, by the same law. Hence, as its apparent size and the whole quantity of light received from it are always proportional, its *brightness* remains the same at all distances, and the sun appears to be no brighter from Mercury than from the earth. This, however, is only true in free space, and not in air, because a portion of the light is *absorbed* in passing through air, as explained in the case of heat, page 11, causing the intensity to diminish rather *faster* than the inverse square of the distance.

The investigation of these effects, and all others deducible from the law of straight-lined motion alone, constitutes the first branch of optical science, called PERSPECTIVE.

The application of this science, when no account is taken of the absorptive power of the medium through which we see, constitutes *Lineal Perspective;* when this consideration is added, it becomes *Aërial Perspective.*

The second science of light, called CATOPTRICS, investigates whatever is deducible from the law of *reflexion*, already explained in the case of heat. See Fig. 1136.

As when a moving body strikes another at rest, the mechanical force is divided and shared between them; so when the action of light, propagated through any medium, arrives at the surface of a new medium either denser or rarer, more or less transparent than the former, its force is divided, a portion entering the new medium, and a portion rebounding into the old. This latter portion belongs to Catoptrics. Its quantity rarely exceeds *half* the original light, except in one case, to be noticed presently, where it includes the *whole* effect. When the portion reflected from any surface, or point of a surface, to the eye is considerable, such surface or point appears *white;* when very little, it appears *dark-coloured;* and *black* when the portion is inappreciable. Hence it is evident that the same surface which appears to be *white* to an eye in one position may appear to be *black* from another point of view, as frequently happens with a mirror, or some particular point thereof, or of any other bright or reflecting surface. But surfaces which are distinguished as *reflective* do not really reflect more light than those which are termed *dull* or non-reflective, provided the depth of colour be the same in all. Burnished silver reflects no more light than frosted silver, nor does the melted surface of sealing-wax than the broken surface of a stick of that substance. Nor do these dissimilar bodies reflect according to different laws or by different kinds of reflection; although such varieties of reflection as the following have been distinguished: — First. The *specula*, or mirror-like reflection, according to the law of equal angles, already explained in the case of heat, Fig. 1136, by which each ray that arrives in one definite direction is reflected only in one direction. Second. The *radiating* or dull reflection, according to a different law, by which each ray is scattered equally in all directions. But in this case it may be proved that a dull and a polished surface alike observe the law of equal angles: their different effects may be thus explained:—a *dull* surface, however smooth to the touch, appears under the microscope to be so covered with roughnesses on a small scale, that the smallest visible portion of it contains not only surfaces turned in all possible directions, but equally in all possible directions. When these are large enough to be visible, the surface is *glittering*, as in refined sugar, fragments of marble, cast-iron, &c.; but all these substances appear to be *dull* when viewed beyond a certain distance, just as all dull surfaces would be glittering if we could place the eye near enough. Each minute surface reflects each ray that falls upon it according to the law of equal angles; but as surfaces lying in all directions exist in each visible point, light is scattered in all directions from each such point, even though it arrived there in only one direction. A reflective surface, as it is called, although not free from roughness, contains in each visible point a greater or less preponderance of surfaces having one fixed direction. But in this, no less than in a dull surface, each point radiates light in all directions, but only because, under ordinary circumstances, it receives light in all directions. Confining our attention to that which comes in one direction, and which is often to be distinguished from all the rest by some peculiarity either of intensity or of quality, this is reflected only or chiefly in one direction; not equally in all, as it would be by a dull surface.

All the appearances of opaque bodies, apart from colour, and all the images of other bodies appearing either behind or before mirrors or reflective surfaces, whether such images be true or distorted representations, erect or inverted, magnified or diminished, may all be accounted for by the law of equal angles, as those of perspective are from that of straight-lined motion.

Only a portion of the light which meets any surface is reflected, the remainder being absorbed or transmitted: when it is absorbed, the substance is said to be *opaque;* but when we can trace it further, the substance is called *transparent. Opacity* and *transparency* are not opposite properties, but only very different degrees of the same property. As radiant heat of a given intensity can penetrate much further through some media than through others before it is entirely absorbed, or stifled, or expended in warming them; so with light. Solar rays, for example, can penetrate through some hundreds of miles of air, but not through the thousandth of an inch of lamp-black or of metal; for however much these two bodies may differ in the proportions of light which they reflect, and consequently in that which they allow to enter, they both agree in stifling the latter before it has

penetrated to any sensible depth within their surface. Most other solids and liquids, however, can be reduced to such a degree of tenuity as not to absorb all the light which enters them, but to allow some of it to emerge on the other side; and as no medium, not even air, is perfectly transparent (for if it were there could be no such thing as aërial perspective), so also it may be supposed that no substance can be perfectly opaque; or, in other words, that no absorption or extinction of light can take place at a mathematical surface; for even the densest metals, platinum and gold, can be reduced to leaves sufficiently thin to transmit a small portion of light. Perhaps no other property is possessed in such various degrees by different substances as their power of absorbing light; light loses less of its intensity in passing through 50,000 miles of matter of Encke's comet than in passing through a few yards of light fog, an inch of glass, or a 300,000th of an inch of gold.

When light passes from one medium into another (unless its direction be perpendicular to the surface dividing them), that direction undergoes a sudden change, which is called *refraction*. The investigation of this property belongs to the third branch of optics, called DIOPTRICS. The new direction assumed by the ray is regulated by the following laws. Let A A, Fig. 1320, represent the surface of calm water, which is necessarily polished, as that of all fluids must be, by the operation of the molecular forces. No light will pass through this surface unrefracted, unless it either descend or ascend perpendicularly, as from P to P′, or P′ to P. Any ray which falls obliquely, as B C, will be suddenly bent into the direction C B″; and if it arrive more obliquely, as D C, it will be *more* bent, taking the direction C D″. It will be seen that in both cases the tendency of refraction is to render the ray more nearly perpendicular to the surface than before. But any ray which proceeds from the water into the air undergoes a contrary effect, being rendered *less* perpendicular to the surface. Thus, a ray ascending in the direction B″C will, on emerging, take the direction C B; and one which, in the water, travelled along D″ C, will, in the air, be bent into C D; the bending in this case, no less than the former, being greater the more oblique the ray may be to the surface. Moreover, it is a law in refraction no less than in reflection, that by whatever path a ray reaches one point from another, by the very same path will a ray travel from the second point to the first. An eye at D″, then, will see the object D, not in the direction D″ D, but in the direction D″ C, higher than its true place; and an eye at D will see the object D″ in the direction D C, also higher than its true place, of which any one may convince himself with a basin of water. An opaque body placed at C will hide D and D″ from each other, though not in a straight line between them; and if it were in the straight line, it would not hide them, for they see each round a corner at C.

The first part of the law of refraction is similar to that of reflection, viz. that the angles of incidence and refraction (*i.e.* the angles which the incident and refracted ray each make with the perpendicular or normal of the surface, or in this case the angles P C D and P′ C D″) are both *in the same plane.* Any ray meeting the surface of a new medium is split into two rays, one reflected and the other refracted; as, for instance, the ray B C into the reflected ray C B′, and the refracted ray C B″; or D C into the two rays C D and C D″. So, also, a ray B″ C will be partly reflected in the direction C *b*′, and partly refracted into C B; or D″ C will be reflected into C *d*′, and refracted into C D. Now, in all these cases, the three rays, incident, reflected, and refracted, will be all in one plane, and that plane perpendicular to the acting surface A A. The angles of incidence and reflection (such as P C D and P C D′) are, as already explained, invariably equal; but that of refraction (in this case P′ C D″) is different from both, but connected with them by this law, that (at the same surface) the *sines*[1] of incidence and refraction, to the same radius, bear a constant ratio to each other, which is always the same in the same two *media.* For instance, in passing through the surface A A, at whatever degree of obliquity, and whether upwards from the water into the air, or down from the air into the water, a ray is invariably so bent that the angle it makes with the perpendicular P P′ *in the air* may be greater than that *in the water;* and that the *sine* of the angle in air may be to that in water (to the same radius) as 4 to 3, which is the ratio that has been determined by experiment. At the surface separating any other two media, a different ratio would be observed with equal constancy.

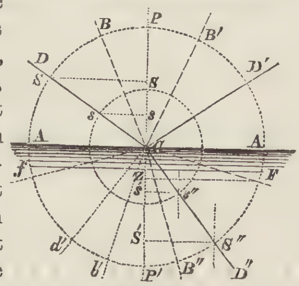


Fig. 1320.

If we want to find the new direction into which any ray, such as D C, will be bent by this surface, we draw a circle round the point C with *any radius,* such as C S, and we find the sine of the ray *in air* (to this radius) to be S S. Therefore the sine *in water* will be $\frac{3}{4}$ of S S. Draw a line parallel with C P′ at a distance therefrom equal to $\frac{3}{4}$ of S S, viz. at the distance S′ S″, and as this intersects the circle at S″, we know that the refracted ray must pass through S″ to make its sine in water (S′ S″) $\frac{3}{4}$ of its sine in air (S S) both to the same radius (C S or C S″). If any other radius had been chosen, as C *s*, it is plain that we should have obtained the same result; for, by the property of similar triangles, if S′ S″ be $\frac{3}{4}$ of S S, then *s′ s″* is also $\frac{3}{4}$ of *s s.*

(1) The *sine* of an angle is any line dropped from a point in one of its legs perpendicularly to the other leg, and may therefore have any length. Thus, the sine of P C D (Fig. 1320) may be either S S or *s s*, or any other line parallel with them, intercepted by the two legs of the angle P C and C D. The sine *to a given radius* is found by drawing a circle with that radius round the angular point, and from wherever this circle crosses one leg dropping a perpendicular to the other. It can therefore only have one length, and (in the same angle) will always bear the same proportion to the radius, however long or short that may be. Thus the sine of the angle P C D to the radius C S is S S, but its sine to the radius C *s* is *s s*.

If we were tracing the course of a ray upwards from the water, as D″ C, then, having found its sine *in water* to any fixed radius, we should make its sine *in air* $\frac{1}{3}$ greater, because the sine in air is always greater than that in water, as 4 : 3; and we should thus find the new direction of the ray to be C D. In this case a very singular effect would take place if the ray were very oblique to the surface, as F C. We should first remark that *no* ray passing from the air into the water, however obliquely, could ever be refracted into the direction C F; for this reason—The sine of no angle can be greater than the radius to which it is drawn; therefore no ray can have its sine to radius C S greater than C S. But its sine in water is only $\frac{3}{4}$ of that in air, and consequently cannot exceed $\frac{3}{4}$ of the radius. Now, the sine of the ray C F, viz. F *z*, is more than $\frac{3}{4}$ of the radius C S; therefore no degree of obliquity of the ray in air will enable it to become so oblique in the water as C F. But a ray may ascend in the direction F C as well as in any other. Now, its sine in air must become $\frac{1}{3}$ greater than F *z*; but this is impossible, for a line $\frac{1}{3}$ longer than F *z* would be longer than the radius C S, and therefore too long to be the sine of any angle to that radius. As this ray, then, cannot be refracted *according to the law*, it is not refracted *at all*, but *totally reflected* in the direction C *f*, the only known instance of total reflection, for none of the light can penetrate the surface A A, which is, in fact, absolutely *opaque* to this light. This phenomenon of *total reflection* may be seen by looking through the side of a tumbler containing water up to its surface, in some such direction as *f* C, when the surface will be seen to be opaque, and more reflective than any mirror, inasmuch as the images in it are perfectly *equal* in brightness to the objects themselves.

At the surface between any other two media, the ratio of the sines would be different; for though all surfaces *reflect* alike (as regards the direction of the ray), all do not *refract* alike. Suppose the ray passed from *vacuum* into *water*, the ratio would be rather greater than 3 : 4, namely 1 : 1·335. In passing from vacuum into air of the common density, the refraction would be much less, and consequently the sines much more nearly equal, viz. as 1 : 1·000294. Now, if the sine in any medium be called 1, the corresponding sine *in vacuo* is called the *index of refraction* of that medium; and is *specific* for each substance, or as constant as its density, expansibility, specific heat, or any other measurable quality. Thus the refractive index of *air* of the common density is 1·000294, that of water 1·335, of crown glass 1·52, of flint glass 1·55. Now, in the case above considered of refraction from air into water, and *vice versâ*, the sines in air and in water are, strictly speaking, as 1·335 : 1·000294; and generally the sines on each side of any surface are *inversely* as the refractive indices of the two media. The refractive indices of a great many media have been measured and arranged in tables. When the density of any substance is increased or diminished, its refractive power is increased or diminished in the same ratio. In these tables it will be observed, *first*, that the index of every medium is greater than 1, because the sine *in vacuo* is always greater than in any medium which has been examined: *secondly*, that few gases or vapours have a higher index than 1·001; few liquids lower than 1·335, which is the index for water, and none higher than 1·7; no solids, unless they contain fluorine, lower than 1·5, with the exception of ice, which is only 1·31; and none higher than 1·6, except the gems, which vary up 1·96; sulphur which is 2·15, phosphorus 2·22. The diamond is 2·44, being the most refractive of transparent bodies, although it is exceeded by a few deeply coloured almost opaque minerals.

It is commonly said that both refraction and reflection occur at such surfaces only as separate media from different densities. But this must be understood of *optical* density,[1] which is by no means proportional to *mechanical* density, at least in different substances; for although a change in the density of any medium causes a proportional change in its refractive index (as when water expands on becoming ice, and has its index diminished from 1·335 to 1·310), yet this by no means applies to different media; for water, which is much denser than oil, is much less refractive. By reducing the refractive indices of bodies in order to ascertain their ratio if they were all of equal density, we are enabled to compare their *absolute* refractive powers, which are found to be closely connected with their chemical properties; *anions*, or electro-negatives, having always the lowest refractive power; and *cations*, or electro-positives, the highest. Refractive power seems to be the only property except weight, which is unaltered by chemical combination; so that by knowing the refractive powers of the ingredients we can calculate that of the compound.

The application of the laws of refraction accounts for numerous deceptive effects seen in the atmosphere, and included under the general term *mirage;* the most familiar of which is the distortion of objects seen through a rising current of hot air, which, from its smaller density, has a lower refractive power than the surrounding cold air, and therefore bends the rays in various directions. It is also plain that the rays of the heavenly bodies coming from space into our atmosphere must be refracted, and thus cause the objects whence they come to appear rather *above* their true place, as the eye at *d*, in Fig. 1320, sees D in the direction *d* C, rather above its true place. This forms one of the sources of error to be allowed for in all astronomical observations; and tables are calculated for finding its amount, depending on the

(1) As it is possible to find two substances which, though very different in their nature, have nearly or quite the same optical density, light will pass from one into the other, unrefracted and unreflected, and the surface between them, however rough, will be transparent and invisible. This remarkable effect may be seen by plunging ground or powdered glass into a mixture of the oils of turpentine and aniseed, in such proportions as to have the same refractive power as glass; or, by rubbing ground glass with wax, which, by filling up its hollows, will render it transparent. This is also the reason that paper, by being wetted or oiled, becomes less white and more transparent, reflecting less light and transmitting more. The mineral called *hydrophane* is another example.

apparent altitude of the object, and the state of the barometer and thermometer. Owing to the very small refractive power of air, however, this error is hardly sensible when the object is high, but increases rapidly towards the horizon, where it becomes 33′, or rather more than the sun's or moon's diameter, so that these bodies may appear just clear of the horizon when they are completely below it. As the density of the air diminishes *gradually* upwards, atmospheric refraction is not, like that which we have just considered, a *sudden* change of direction, but the ray actually describes a *curve*, being refracted more and more at every step; and this applies equally to the light from a distant terrestrial object which is either lower or higher than the eye, because it must pass through air of constantly increasing or diminishing density. This refraction has therefore to be allowed for in LEVELLING, which is done by assuming that the light from a distant object comes to us in a line arched or curved upwards, the radius of which is about seven times that of the earth.

The application of these laws of Dioptrics has also led to the understanding of the mechanism of the *eye*, and hence to the imitation thereof by *lenses*, affording the remedies for its infirmities of *long* and *short sight*, and disclosing the wonders of the *telescope* and the *microscope*.

In order to understand the action of lenses, we must remember that, as a lens has necessarily *two* refracting surfaces, the direction taken by a ray after passing through it must depend mainly on the relative inclination of the two surfaces to *each other* at the points where it crossed them. Sometimes one surface partly or wholly undoes the effect of the other, and sometimes adds to that effect.

Let us first examine, then, the progress of light through a piece of plane or parallel glass, of equal thickness throughout. Let A A and B B (Fig. 1321) represent portions of the two surfaces of such glass, and let a ray from R fall obliquely on the surface A A at a. To find tne new direction it will take, we must first draw $p\,p$ through the point a, perpendicular to the refracting surface A A. Now, by the first law of refraction, we know that the refracted ray will be in the same plane which contains the incident ray R A, and the perpendicular P P. In this plane, therefore, and with any radius, we draw a circle round the point a, and we find the sine of incidence to be x. Now, by referring to the tables, we find the index of the refraction of *glass* to vary from 1·521 to 1·58, according to the *kind* of glass. But, for simplicity sake, we may suppose it to be generally about $1\frac{1}{2}$ times that of *air*. Therefore the sines in air and in glass (to the same radius) will be as 3 : 2; and by making the sine in glass (viz. y) equal $\frac{2}{3}$ of x, we find the new direction of the ray to be $a\,b$, meeting the second surface B B at b. Here we erect a new perpendicular P′ P′, and draw a new circle, which is obviously in the same plane with the former circle round a, and (supposing both circles to be equal) it is plain that the sine y' in the second circle is equal to y in the first. Now, the new sine in air (viz. x') must be $1\frac{1}{2}$ times the length of y' or y, and therefore will just equal the original sine x. Hence we see that the emergent ray b R′ will have the same direction as the original incident ray R a, though not in the same line with it. Thus we see that a ray can suffer no permanent change of *direction* by passing through a parallel-sided plate of any medium, although it suffers a small lateral displacement depending on the *thickness* of the plate, which displacement may be easily seen in viewing this page through a piece of *thick* glass.

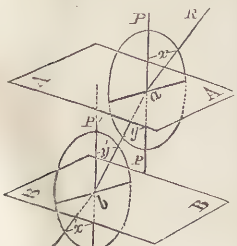


Fig. 1321.

This property of parallel-sided glasses, by which their second surface exactly undoes the refractive effect of the first, renders them so well adapted for windows. But by the same reasoning which shows us that two parallel surfaces will compensate each other's effects, we shall also see that, to produce this compensation, the surfaces must be parallel; so that glass of unequal thickness displaces and distorts objects seen through it. Any glass having two *plane* surfaces, not parallel, is called a *prism;* and it permanently alters the direction of every ray passing through it, the change being greater in proportion as the inclination of the two surfaces[1] is greater. On looking through it, all objects are seen removed from their true place towards the *base* or *thicker part* of the prism, whether that be turned upwards, downwards, or to either side.

But however much a prism may change the general direction of each *pencil*[2] of light that passes through it, it can effect no change in the relations of the various rays which compose each pencil. These all proceeding from one point necessarily diverge, but the further we recede from their point of origin, the less divergent will any small portion of them be; and when the point is at a vast distance, as in one of the heavenly bodies, all the rays of each pencil may be regarded as *parallel*, although the different pencils have different directions.

Now, no *plane* surface or combination of plane surfaces can ever increase or diminish the divergence of a pencil passing through them, still less render a divergent pencil parallel, or *vice versâ;* and as in the eye and all other optical instruments it is necessary that this should be done, and even that they be made to *converge* and meet or *focalize* in one point, and

(1) Technically called the *refracting angle*.

(2) *Pencils* of light are so called from their property of *painting* on a screen an image or picture of the points whence the pencils originally came. This resemblance is not seen in any one point alone, but when the other pencils, proceeding from all the surrounding points of the object, are each separately concentrated on as many different points of the screen, all these points or *foci* shine with the same qualities and intensities of light, relatively to each other, as did the corresponding points of the object; so that they must form an exact picture thereof, such as is painted on the retina of the eye, and in that beautiful toy the *camera obscura*, which is an imitation of the eye.

again diverge therefrom as from a new source, advantage is taken of the refractive effect of the *curved* surfaces of *convex* and *concave lenses.* It is obvious that a pencil of parallel rays meeting with a curved surface must all have different inclinations thereto, and consequently all must undergo different amounts of refraction, so that they can be no longer parallel after passing through the surface. Now, whether they be entering or emerging from the surface, that is, whether they pass from a rarer medium into a denser,[1] or *vice versâ;* in either case they will be rendered *divergent* if the surface of the denser medium be concave, and *convergent* if it be convex. Let us further inquire into the opposite effects produced by these surfaces upon a *single* pencil of light, the rays of which are not parallel, but either *divergent,* or already rendered *convergent* by the action of some other surface.

First. By convex surfaces every pencil already convergent is rendered still more so. Thus the rays B (Fig. 1322), proceeding through a convex surface to A, are made to converge more quickly than before, so as to focalize sooner than they would otherwise

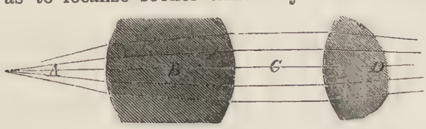


Fig. 1322.

have done. With regard to divergent rays, they are at least rendered *less* divergent by passing through this kind of surface. Thus the rays at A passing to B have their divergence diminished. But in certain cases, *viz.* when their original divergence is not too great, it may be altogether destroyed, and they may be rendered parallel, as the rays B proceeding to C; and if their divergence had been still less, or the surface more convex, or the medium more refractive, they might at once be changed from a divergent into a convergent pencil, as the rays from B passing through *two* convex surfaces to D, become convergent, an effect which might have been produced by a single surface, if it had been sufficiently powerful.

Secondly. By concave surfaces, on the contrary, a divergent pencil is made to spread still faster, as in going from B to A, Fig. 1323. And a convergent

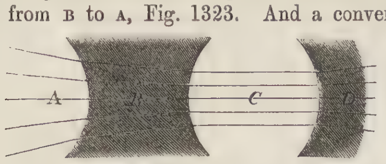


Fig. 1323.

pencil has either its convergence diminished, as from A to B (thereby delaying its focalization, though not preventing it), or its focalization is prevented by rendering it a parallel pencil, as in passing from B to C; or if the surface be strong enough, the pencil is changed from convergent into divergent, as by the joint action of the two surfaces B and D.

(1) *Optical* density or refractive power is here meant, which is not proportional to mechanical density in different substances. For example, oil is mechanically rarer, but optically denser than water.

This effect of convex and concave surfaces is not so easily observed as their magnifying and diminishing power. To illustrate this, let us suppose that the lines at A, Fig. 1322, instead of representing different rays from the same pencil, to be different pencils coming from various points of a certain object to the eye, situated somewhere beyond B; as they proceed from several points to one point, they must be convergent. By passing through a concave surface they are rendered less convergent, and it is evident that the eye will receive the top pencil as if it came from a point lower than that of its real origin, and the bottom pencil as if it came from a point higher than it actually does. Thus the top and bottom of the object will be seen nearer together than they really are; and the sides being also brought nearer to each other, the object will appear to be *diminished.*

Let us view the lines at B, Fig. 1323, in the same manner as representing distinct pencils, but proceeding through a convex surface to an eye placed at, or beyond A. As their original convergence is increased or hastened, they all enter the eye as if they came from points more distant from each other than is actually the case, and hence the object appears to be *magnified.* This magnifying effect is, however, too small to be turned to any useful account, and must not be confounded with the magnifying power of telescopes and microscopes, which, although produced generally by the combination of convex lenses, depends not at all on this last-mentioned principle, but on an application of that first described, viz. their action on the different rays of the same pencil, not on different pencils.

These details will enable the reader to understand something respecting the mechanism of the first of all dioptric instruments, the *eye,* and the use of *spectacles;* as also the principle of *achromatism.* It will be seen that in every respect the action of *convex* and of *concave* media (in vacuo) is opposite, the former constantly tending to focalize light, and the latter to prevent or retard its focalization. For the sake of orevity let us call the former effect *positive,* and the latter *negative.* There is also this advantage in doing so; for as the surfaces of lenses generally separate one medium from another, and not from a vacuum, one medium must always be convex and the other concave; but we call the surface convex or concave according as the *denser,* or rather the *more solid* medium is so. Now in this sense, a convex surface does not always produce the positive effect, and *vice versâ;* for let a convex lens or magnifying glass be immersed in oil of aniseed or of cassia, and it will act as a concave lens or diminishing glass; for these oils, although mechanically rarer, are optically denser than glass, so that the lens acts as a partial vacuum in the oil, and its convex surfaces have less effect than the concave surfaces of the oil. For the same reason, a concave lens plunged into these oils will magnify. This confusion between the mechanical and optical meanings of the terms *convex* and *concave,* may be avoided by substituting the terms *positive* and *negative.*

The eye consists of a spherical box, into which the

light is admitted through a hole, called the *pupil,* and passing through three transparent media, called *humours,* all separated by positive surfaces, the light is by their action focalized (each pencil to a different point), in the *retina,* or screen of nerve, which is spread out on the back of the box to receive and perceive them. Hence it is evident that the rays of light must form on this screen a picture similar to that in a camera obscura, and to produce distinct vision the picture must be distinct, that is, the rays of each pencil must neither focalize and cross, before they arrive at the retina, nor yet arrive there without focalizing; for in either case they will not be separated from every other pencil, for they will not be concentrated on one *point,* but be spread over a small circle, so as to mingle with the surrounding pencils. Now these are the two opposite defects, called *long* and *short sight,* which are corrected by placing before the eye a positive or a negative lens, the former accelerating and the latter retarding the focalization of the rays. The short-sighted eye overdoes its work, for it focalizes the rays of each pencil too rapidly, and thus separating all the pencils too soon, allows them to mix again before arriving at the retina. This may be remedied in two ways; *first,* by bringing the object very near, so that the rays received from each point may be more divergent than usual, and may therefore converge less quickly after refraction by the humours of the eye; or *secondly,* by looking at distant objects through a *negative* lens, by which the rays of each pencil naturally almost parallel, are rendered divergent, as if they came from a nearer object, and are therefore, as before, more slowly focalized.

The long-sighted eye fails to effect the complete separation of the various pencils, before they reach the retina, unless they come from a very distant object, so as to consist of nearly parallel rays, which require less refraction to focalize them, and are, therefore, sooner focalized than the more divergent ones coming from nearer objects. In order to focalize the latter, the eye must be aided by another positive lens, in addition to its own positive surfaces, which are not sufficiently powerful.

A healthy eye cannot see objects distinctly nearer than 6 inches, because the rays of each pencil are too divergent to be focalized soon enough to give a distinct picture on the retina. This may be remedied, therefore, by an extension of the same principle applied for the correction of long sight, viz. by helping the eye to focalize these pencils by the aid of a positive lens, which performs part of the work, and leaves the other part to be done by the eye. Thus, by using a lens powerful enough, we may see almost as near as we please, even at $\frac{1}{4}$th or $\frac{1}{8}$th of an inch. Such a lens, applied at once to look at an object, forms a *simple microscope,* and when used for looking at the optical image formed in a compound microscope, or in a telescope, it constitutes the *eye-glass* of those instruments.

No healthy eye can see very distant objects, such as the heavenly bodies, distinctly through a positive lens, however small its power, because the rays of each pencil, already parallel, are by the lens rendered convergent, a state which they never can have in nature, and which the eye is no way fitted to receive, for being already partly focalized, this work will be completed by the eye too soon, and they will cross before arriving at the retina.

From all that has been said, it will be evident that a positive and a negative surface of equal power will neutralize each other, as in a *watch-glass,* which has just the effect of a plain glass.

The *focal length* of a surface or lens (if positive) means the distance at which it will focalize a pencil of previously parallel rays, or at which, therefore, it will form on a screen a distinct picture of any very distant object, such as the sun. This is also the distance at which it must be placed from the source of any divergent pencil, to render it parallel; consequently, the greatest distance at which objects can be seen distinctly through it; for if they be removed further, the rays of each pencil, falling on the lens with less divergence, will be rendered convergent, and therefore unfit to afford distinct vision.

But the focal length of a *negative* surface or lens is equal to that of such a positive one as will just neutralize it, and produce the effect of a plain glass; or it is the distance at which a pencil, which it renders parallel, (or just prevents from focalizing,) would have focalized, if not intercepted by it.

Now the focal length of a spherical surface,[1] whether positive or negative, depends jointly on its radius, and on the ratio between the refractive indices of the two media; but if this ratio be as 3 to 2, (which those of air and glass are very nearly,) the focal length of any surface is *twice* its radius.

All the complex rules commonly given for finding the *combined* focal length of two surfaces, or that of the different kinds of lenses, [see Lens,] may be dispensed with by attending to the following simple principle:—The *effects* of surfaces are *inversely* as their focal lengths, and the combined effect of two *similar* surfaces must be the sum of their separate effects, while that of two *dissimilar* surfaces is the difference of their separate effects. Therefore, the combined focal length of two similar surfaces is the *reciprocal of the sum of the reciprocals* of their separate focal lengths. Thus, to find the focal length of a lens whose surfaces have the focal lengths of 6 and 4 inches, both being positive or both negative; add their reciprocals, viz. $\frac{1}{6}$th and $\frac{1}{4}$th, which gives $\frac{10}{24}$ths, the reciprocal of which is $\frac{24}{10}$ths, or 2·4 inches, the answer. But if one surface were positive and the

(1) The surfaces of lenses are always *spherical,* because it has not yet been found practicable to give them any other figure accurately. [See Lens.] But it can be proved that they ought to be sometimes portions of *oblong spheroids,* and sometimes of *hyperboloids,* according to the purposes for which they are intended. In consequence of their not having these forms, they focalize imperfectly, which defect is called their *spherical aberration.* By observing particular ratios, however, between their curvatures, although spherical, their errors may be made partly (or in some cases wholly) to compensate each other; and this is one of the chief objects aimed at in the construction of the best class of telescopes.

other negative, (as in a periscopic lens,) subtract $\frac{1}{6}$th from $\frac{1}{4}$th, which leaves $\frac{1}{12}$th, the reciprocal of which is 12 inches, the answer.

We see, then, from the foregoing details, that when the various pencils coming from any object are separately focalized in different adjoining points of space, these points form a repetition or *image* of the object suspended in space, and differing from a real object only in this; that each point of a real object radiates a *sphere* of light, so as to be seen in every direction, whether the eye be above, below, or on any side of it; while each point of an optical image radiates only a *cone* of light, so as to be seen only by an eye placed in that cone.

We have seen how this image may be larger or smaller than the object, and may be brought as near to us as we please, so that we may examine details in it which are invisible in the real object, on account of its distance. The image formed in the compound microscope is *larger* than the object; in the telescope it is incomparably smaller; but in both it is brought very near to the eye, too near to be seen without the intervention of an eye-glass, the action of which is, by combining with that of the lenses of the eye itself, to render it for the time unnaturally short-sighted; for by adding other lenses to its own, the eye can be made to see at the distance of an inch, or even $\frac{1}{10}$th of an inch, as in using a simple microscope already alluded to.

Although refraction is a property common to light of all kinds, yet this property is not possessed *equally* by different kinds of light. As sounds differ in many respects besides loudness, and as radiant heat (apart from any difference of intensity,) differs in the qualities of refrangibility and absorbability by different media, so also do rays of light differ in the degrees of these same qualities, independently of their difference of brightness; and these differences, in so far as they are distinguishable by the eye, constitute *colour*. Differences of quality, not distinguishable by the eye, constitute *polarization*.

The law of refraction, that the sines of incidence and refraction always bear the same ratio at the same surface, is true only as regards rays *of the same colour*, or coming from objects of the same colour. Moreover, light, which we call *colourless* (as that coming immediately from the sun), really contains light of all possible colours so mixed as to neutralize each other. This capital discovery was made by Sir Isaac Newton in the following manner:—Having closed the windows of his apartment, he made a small hole in the window-shutter, so as to admit a sunbeam R, Fig. 1324, which, proceeding in a straight line, illuminated a spot on a screen placed to receive it at A. Now, by means of a prism, which we have seen effects a permanent change in the direction of the light that passes through it, we can turn aside this sunbeam in every direction. Thus, if the base of the prism be downwards, the beam will be turned downwards; but a prism turned base upwards, as at P, will refract the beam upwards, so that it will no longer illuminate the spot A, but some spot much higher, as S. Now, it is very remarkable that this spot S, instead of being similar to A in shape, is greatly *elongated*, its breadth remaining unaltered; and, whereas A was colourless, the lengthened spot S exhibits a continued gradation of the most intense colours, the lower end being *red*, which passes upwards into *orange*, this into *yellow*, then *green*, *blue*, *indigo*, and *violet*, which is at the upper end. The very same colours will be seen, and in the same order, whatever way the prism may be turned; for, whether the spot S, which is called the prismatic *spectrum*, be above, below, or on either side of A, its red end will always be *nearest*, and its violet end *furthest* from A.

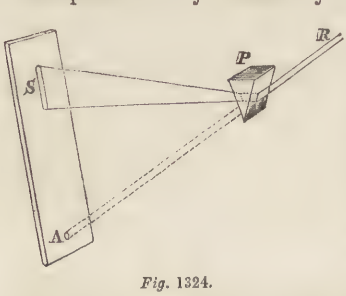


Fig. 1324.

Hence we see that the various rays composing the parallel pencil R do not remain parallel after refraction, even by two *plane* surfaces (contrary to what has been advanced Fig. 1321), and consequently these rays must have suffered *different* amounts of bending, though falling on the prism under precisely similar circumstances; and this will be found to be true also in every other case of refraction, whether produced by a prism or a single surface, and whether by glass or any other solid or liquid medium. The same rays that are most bent by passing from air into glass are also most bent in passing from glass into air, or into water, or any other medium, and are therefore said to be the most *refrangible*.

Moreover, it appears that the rays which are *least* bent are always *red*, those *most* bent always *violet*, and the others of intermediated colours, though before separation they were colourless. It became an interesting question, then, whether, if reunited, they would again compose colourless light; and this Newton proved by many convincing experiments, the most complete of which perhaps consisted in receiving the divergent beam at S, on a convex lens, when the focus at which all the coloured rays met was found to be perfectly colourless.

If, however, in this last experiment, the lens be not wide enough to include the *whole* of the coloured beam, or if a portion thereof be purposely intercepted, the focus of the remainder will not be white, but tinged with some colour, which will be pale if only a *small portion* of the spectrum be thus intercepted, but more decided the more of the spectrum be omitted from its composition; and there is no colour, tint, or shade, in the whole circle of nature or art, which may not be thus *exactly* reproduced by a mixture of part only of the components of white light.

This important fact may be further shown thus. If we look through a prism at some small *white* object or spot on a *black* ground, it will be seen not only out of its place, but lengthened, and coloured with the entire series of prismatic colours, forming a complete

spectrum, of which the red end is nearest the true place of the spot, as seen without the prism. The same will occur if the spot be *grey* or of a neutral tint, showing that, though it reflects less light than the white object under the same circumstances, yet it reflects the same kind of light, or a mixture of the same colours. In fact, a good neutral tint should differ in no respect from a white *less illuminated,* so that, by regulating the intensities of light which they receive, they may be made to appear exactly alike. But, if the object examined through the prism be *coloured,* it will not be lengthened so much as the white or grey object; for some portion of the spectrum, either one end, or both ends, or the middle, will be *missing*, and the portion which appears will show what portion of the complete, or solar, spectrum must be focalized, apart from the rest, to imitate the colour of this object.

Now, if the object here used be of a very pure and intense colour, such as vermilion or ultramarine, it will scarcely appear elongated or at all changed in appearance, showing that all the rays coming from it are nearly of the same kind and equally refrangible. But Newton showed the different refrangibilities of these two colours by the following very simple and conclusive experiment. A little rectangle of paper, coloured half red and half blue, as B R, Fig. 1325, was placed on a black ground and viewed through a prism. When this was so turned as to see the paper above its true place, as at *B R*, the blue half was seen raised higher than the red half, as here shown; and when both were depressed below their true place, as at *b r*, the blue was seen to be depressed the lowest, so that in both cases it was more displaced, *i. e.* its rays were more refracted than the red.



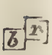


Fig. 1325.

If this experiment be varied by using the two colours finely powdered, and mixing them together so as to appear *purple,* neither the red nor the blue grains being distinguishable by the eye, the prism will nevertheless effect their complete apparent *separation,* so that, if the spot of purple be small, it will appear divided into two distinct spots of *red* and *blue;* but, if it be too large for its two images to be detached, it will only appear *fringed* with red on the upper edge and blue on the lower, or *vice versâ,* the middle part, where they overlap, remaining purple. On this principle, therefore, we may easily explain all the coloured fringes seen to surround objects viewed through a prism, a lens, or any other glass of unequal thickness. All this is due to the *decomposition of light* by refraction, in consequence of its rays having different degrees of refrangibility and different colours.

The ratio between the sines, in any two media, being different for rays of different colours, it follows that the index of refraction given in the tables above mentioned for each medium only applies to rays of a particular colour, viz. those of the *mean* refrangibility, or *middle colour* of the spectrum, viz. green. Thus the index of water for these rays is 1·335851, but for some of the violet rays it is more than 1·344, and for some of the red less than 1·330; and there exist rays having every possible index of refraction (by water) between these two extremes.

A similar difference, though not in the same ratio, generally a greater, exists between the refrangibilities of these rays by every other medium, whence Newton concluded that the focal length of a curved surface, or of a lens, must be different for different colours, and that, as the light of most objects contains rays of various refrangibilities, it cannot be truly focalized to one point by any lens, thus accounting for the confusion of colours seen at the edges of the image formed in a telescope, which confusion, and consequent indistinctness, was at that time the greatest obstacle to the progress of astronomical discovery. He tested the truth of this conclusion by the following simple experiment, among many others:—

Let A B, Fig. 1326, represent two candles, and L a convex lens placed at an equal distance from both, viz. about twice its focal length, or rather less. A pencil of rays from the candle A will be brought to

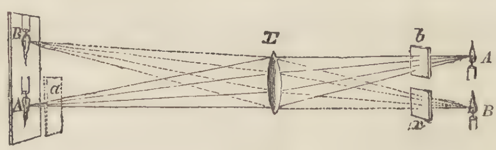


Fig. 1326.

a focus at some point A′, where a white screen must be placed to receive it, and a pencil from B will likewise be focalized at B′ on the same screen. Now, for the same reason that these foci are at different spots, all the innumerable pencils coming from the different points of each flame will be concentrated on different points of the screen, so as to form an exact image of the candle, if the screen be at that precise distance from the lens at which the rays focalize. As the rays from the lower candle, however, go to the upper image, so those from the foot of each flame go to the top of the image, and *vice versâ,* so that both the images are inverted. Now, place before the two candles a blue and a red glass, as *b r*, the images will of course assume the same colours; but it will now be found impossible to place the screen in such a position as to make *both* images distinct. This can only be accomplished by receiving them on separate screens, viz. the blue image on a screen *a* rather *nearer* the lens than that which receives the red image. They will then be more distinct than they can ever be made to be without the coloured glasses.

If we point a common (non-achromatic) telescope to a blue and a red handbill at a short distance, we shall have to draw it out to a greater length in order to read the red than the blue bill. But with this precaution both can be read at a greater distance than a white bill. The same difference will be observed in looking at the sun with a blue or a red darkening glass.

For the same reason the focus of a burning-glass, which is in fact an optical image of the sun, is never perfectly distinct, but always confused by a blue or a

red border, because the various coloured rays of which sunlight is composed cannot all be focalized at once.

As the same cause for imperfect focalization exists in every refractive medium of which a lens could be formed, Newton concluded that no good telescope could be made on the dioptric principle, and that the only perfect focus would be that formed by *reflection* from mirrors or specula, as explained in the case of HEAT, Fig. 1137; for the law of reflection, unlike that of refraction, is the same for *all* rays, of whatever colour. He therefore turned his attention to devising a telescope that should act by *reflection*, and soon invented that noble instrument by which, almost without a change, except in size, the latest discoveries of Herschel and Lord Rosse have been made.

But we owe this grand invention to an oversight of Newton; for soon after his death it appeared, from a closer examination of the phenomena of colour by Euler and others, that what Newton had regarded as impossible, viz. refraction without dispersion of colours, was possible; and another Englishman, Dollond, had the merit of first accomplishing this by an application of the same abstract principle which is displayed in the compensation pendulum, and may be thus exemplified. Although we can find no metal which does not expand by heat, so as to be no longer in summer than in winter, yet, because all metals do not expand in the same ratio to their entire length, we can so combine them as to form a pendulum whose length shall never vary; for its length can be made to depend on the *difference* between the lengths of two bars of different metals, which, though of unequal lengths, may yet expand by an equal increment, for the same increase of temperature, so that their difference may remain invariable. In the same manner, although we know of no solid or liquid which refracts all the colours equally, and although the same colour which is most refrangible by glass is also most refrangible by water, oil, or any other medium, yet, because the ratio between the refractions of the *most* and *least* refracted rays is not the same for every medium, we have the means of so combining two media as to refract all the colours equally. For instance, a certain kind of *plate glass* is found to bend the most refrangible violet rays always $\frac{1}{30}$th more than the least refrangible red rays. This is expressed by saying that its *dispersive power* is $\frac{1}{30}$th, or 0·033. Suppose we have a kind of *flint glass*, which bends the violet rays $\frac{1}{20}$th more than the red, or has a dispersive power of 0·05. It is evident that, if we make a prism of each kind of glass, with such shapes that both shall bend the rays equally, say 30° out of their direct path, both will not form spectra of equal length; for one spectrum will be $\frac{1}{30}$th of the whole refraction, or 1° long, while the other will be $\frac{1}{20}$th, or $1\frac{1}{2}$° long. But let the two prisms have such shapes that, while one of them (the flint) refracts the ray 20°, the other (the plate-glass) shall refract it 30°; then both will produce an equal dispersion of 1°. Consequently, if both be placed together in such positions as to refract in opposite directions (one 30° to the right and the other 20° to the left), the latter will not undo the refractive effect of the former, but will leave the ray still bent 10° to the right, and yet their dispersive effects, being each 1°, will entirely compensate each other; so that a refraction of 10° will be produced without any dispersion at all. The same principle is applicable to any other refracting instrument, such as a lens; and thus white or other mixed light is focalized without separating its component colours, and lenses are made to give an *achromatic*[1] image as well as mirrors.

Experiments and computations without end have occupied opticians, ever since this discovery, to find what materials and what curvatures in the lenses of a telescope will render it most nearly *aplanatic*, or free both from the chromatic and all other errors. On the whole, refracting telescopes are now brought to greater perfection than reflecting ones, although they cannot be made so large.[2]

We have seen, then, that the different qualities of light which we call *colours* all exist in common solar light, and are separated therefrom by virtue of their possessing different degrees of refrangibility, and also of absorbability by material media. The order of their refrangibility is the same in all media, but that of their absorbability is different in each medium. Some media have no preference for one quality of light more than another, but absorb them all equally; such are called *neutral* or *colourless*; the quality of colour in bodies is due to the preference they have for light of certain refrangibilities rather than others, so that the least absorbable rays are left either to be reflected from their surface, or transmitted through their substance to a greater depth than the more absorbable

(1) *Achromatic* (from *α*, *not*, and χρῶμα, *colour*), having none besides its proper natural colours; no rainbow-like fringes.

(2) The largest achromatic telescopes, such as those at Dorpat and Kensington, have each a clear opening of 13 inches, while that of Lord Rosse's reflector is 6 feet. Taking the diameter of the pupil of the eye at $\frac{1}{8}$th inch, the former instruments admit 10,816 times, and the latter 331,776 times the quantity of light which is received from any object by the unassisted eye. But as every speculum absorbs about half the light that it receives, the latter number must be reduced to 165,888. These numbers, then, show how much the area of any object may be magnified by these telescopes without rendering it less bright than it appears to be to the naked eye; and their square roots, 104 and 407, show their magnifying powers in such a case. We may also, from the size of the aperture of any other telescope, estimate what is called its *absolute* or *penetrating* power, which is independent of its length or internal arrangements, and depends solely on the size of the object glass. The number obtained by the above rule shows how many times further any object can be seen with the telescope than without it, supposing its brightness to remain the same at all distances, as it does in vacuo. The magnifying power is totally independent of this, and can be made as great as we please, however small the telescope; but it is obvious that as long as the quantity of light admitted is the same, the more the image is enlarged the fainter will it be, its brightness being always proportional to the quotient of the absolute power divided by the magnifying power. If the latter exceed the former, as it does in astronomical telescopes, the object will be less bright than to the naked eye; but if the absolute exceed the magnifying power, the object will be seen brighter with the telescope than without it; this is an essential condition in what are called *night-glasses*.

The magnifying power of a telescope may be found by pointing it to a brick-wall, and fixing it very firmly. By looking with one eye through the telescope, and with the other along its side, we may count how many courses of bricks seen by the naked eye are comprised in the height of one course seen through the telescope.

rays can penetrate; and in either case we name the colour of the body after that of these least absorbable rays. Thus, red glass is so called because it allows the red rays to penetrate through a greater thickness of it than the other rays; but at a certain thickness even the red rays would be all absorbed like the rest, and we should call the glass black. So, also, with the reflected colours of bodies which are generally, though not always, similar to the transmitted ones.[1]

That no body, unless self-luminous, can appear of a colour not existing in the light that it receives, will be abundantly proved by observing the appearances of coloured bodies held in the rays of the prismatic spectrum. It will be found that no such body can ever appear of a different colour from the rays that fall on it, though it may appear of any *shade* of that colour, even down to *black*, if it has not the property of reflecting any sensible quantity of light of this particular refrangibility. Thus the flower of a scarlet geranium held in the green rays and receiving no other light cannot be distinguished from black velvet.

Hence, if a room be illuminated with light of one definite refrangibility, all distinction of colour in that room will be lost, and the most brilliant and variously coloured objects will all appear in mere *shades*, as in a drawing. Such light may be obtained from a lamp fed with a solution of common salt in alcohol. Now, if into a room so lighted there be thrown a few rays of common light, as, for instance, from a dark lantern with holes in it, the spots on which they fall will appear in their natural colours, like spots of bright colours sprinkled over an Indian-ink drawing.[2]

It is doubtful whether any source of light, however, emits rays of only one definite refrangibility; generally speaking, it includes rays of every possible degree of refrangibility, within certain limits; but in the above case these limits are very narrow. In the light of other artificial sources they are wider, and widest of all in solar light, which includes not only all the colours visible to the human eye, but also rays both *more* and *less* refrangible than any that affect our optic nerve. These rays are accordingly invisible to us, and have only been discovered by their effects on other bodies. Those which are more refrangible than violet light are detected by their action on photographic preparations, and by producing other chemical changes, whence they are called the *chemical* rays. [See PHOTOGRAPHY.] Those rays which are *less* refrangible than any visible rays (even the red) have all the properties of *radiant heat* coming from bodies of a lower temperature than 800° Fahr. Such heat is less refrangible than red light, and we have already seen that common radiant heat, like common light, is a mixture of rays of various refrangibilities. Now, if the temperature of a radiating body be increased, it emits, in addition to the rays previously emitted, others of a higher refrangibility, till, when it attains the temperature of 800°, some few of its rays become as refrangible as the least refrangible rays of light, and accordingly become like them *visible*, and affect us with the same colour, so that the radiating body is then said to be *red*-hot. If it be heated more, it emits, in addition to the red, still more refrangible rays, viz. *orange;* then (at a higher temperature) *yellow* rays are added, and so on, till, when the body is *white*-hot, it emits all the colours visible to us; and in some cases (of very intense heat) even the invisible chemical rays, more refrangible than the violet, are emitted, though in less quantity than in the solar rays. Thus light appears to be nothing more than visible heat, and heat invisible light, their difference being only in the *degree* of certain qualities, and in the human eye being fitted to perceive one and not the other, as the ear can appreciate vibrations more rapid than 16 in a second, and not less rapid ones.

Of the various rays composing solar light, the most visible to the human eye are the *yellow;* but those which have the greatest heating effect are the faintest red, or rather those *invisible* rays which are a little less refrangible than the red. Hence bodies which absorb the red rays become more heated by the sun than those which reflect them; *blue* cloth, for instance, becoming sooner hot than *red* cloth of the same depth of colour.

The foregoing details (for which the Editor is chiefly indebted to his "Introduction to the Study of Natural Philosophy," published in Weale's Rudimentary Series) will assist the reader in understanding the principles on which a variety of optical instruments employed in the useful arts depend. There are, however, certain practical applications of our knowledge of the laws of light and colour which require some further notice. The assortment and arrangement of colours in the arts and manufactures is a subject which, notwithstanding its acknowledged importance, has received but little attention in this country. Persons who have a natural taste, an *eye for colour* as it is called, are able so to group and arrange the colours, patterns, and goods at their disposal, as to produce pleasing and harmonious effects; while others who are not so gifted, produce by their arrangements a discord to the eye of the colourist, which is analogous to the effect produced on the musical ear by instruments out of tune. The study of the various phenomena of colour is a delicate, and in some respects, a difficult one; but from the time of Newton's capital discovery of the compound nature of light, the subject has engaged the attention of scientific men. Among those who have laboured in this important field with success, M. Chevreul is eminent; and we propose to give a very brief sketch of that part of his inquiry which relates to the influence which two colours may exercise upon each other when seen simultaneously. The reader who is at all interested in the subject, will do well to

(1) There is a kind of glass common in the shops which transmits *orange* but reflects *green* light; and another whose transmitted colour is *yellow* and the reflected colour *blue*.

(2) In such a light, the absence of all distinction of colour will not hinder us from performing all the most delicate offices of vision, as reading, working, drawing, or *shading* a drawing; whence we may understand how such operations are performed by those who have the singular defect of *colour-blindness*, or insensibility to differences of colour, as was the case partially with Dr. Dalton, who could only distinguish the fruit of a cherry-tree from its leaves by their form.

study M. Chevreul's large work, the title of which is given below.[1]

It has been already shown that a ray of white light can be decomposed or resolved into seven coloured rays: viz. *red, orange, yellow, green, blue, indigo,* and *violet:* that of these seven colours, the *red*, the *yellow*, and the *blue*, are *simple* or *primitive* colours, capable by their combination of forming *white* light; the other four coloured rays being formed by combinations of two of the primary colours: thus, the combination of *yellow* and *red* only produces *orange;* of *yellow* and *blue*, *green;* while *red* and *blue* produce *violet.* The rays comprised in the same group, the *red* rays for example, are not identical in colour; they differ more or less among themselves, although the sensation produced by each one is known by the term *red*.

When light is reflected by an opaque white body, the differently coloured rays are reflected in the proportion to constitute white light; but if light falls upon a body which entirely absorbs it, as in penetrating a perfectly dark hole, such body appears black, and cannot be seen unless it be situated near other bodies which reflect light to it. When light falls upon a coloured body which does not entirely absorb it, there is always some reflection of white light, and of light of the same tint as that of the absorbing body: if the rays absorbed by the coloured body be united to the coloured reflected rays, they will form white light. These reflected rays are said to be *accidental* or *complementary* to the absorbed rays, and differ with the colour of the body on which the rays fall.

If the *blue* and *yellow* rays be absorbed, then the reflected *red* ray is the accidental or complementary colour.

If *blue* and *red* be absorbed, *yellow* will be reflected.

If *yellow* and *red* be absorbed, *blue* will be reflected.

If *red* be absorbed, *green* will be the complementary colour reflected.

If *yellow* be absorbed, *violet* will be reflected.

If, therefore, we wish to produce white light from any coloured ray or rays, we must add thereto the complementary ray.

Complementary colours may be seen by fixing the eye steadily upon a coloured object, such as a wafer upon a sheet of white paper; a ring of coloured light will play around the wafer, and this ring will be complementary to the colour of the wafer; a *red* wafer will give a *green* ring; a *blue* wafer an *orange* coloured ring, and so on. Or if, after having regarded the coloured wafer steadily for a few seconds, the eye be closed or turned away, it will retain the impression of the wafer, not in its own, but in its complementary colour. Thus, a *red* wafer will give a *green* spectrum, &c.

It is on the principle of complementary colours, that two colours or two different shades of the same colour placed in juxtaposition heighten each other's effects. For example, take two bands O and O′ of the same colour and identical, and two other bands P and P′ of another colour and identical; they must be ½ inch wide, and 2½ inches long, and they may be formed of stuff, paper, ribbon, &c. The band O′ is to be gummed to a card with O at the distance of $\frac{1}{20}$th of an inch from it; the band P is to be placed so as to touch O, and lastly P′ is to be gummed on at the distance of $\frac{1}{20}$th of an inch from P. Now, if we look at the card in a certain direction, and during some seconds, we shall generally see *four differently* coloured bands. It will be observed that O′ and P′ serve as terms of comparision to judge of the modifications experienced by O and P in their juxtaposition.

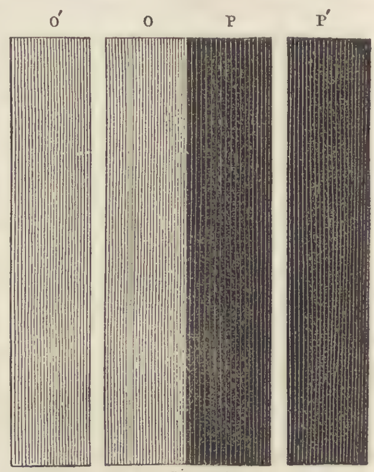


Fig. 1327.

In the following seventeen observations, the colours named in the left-hand column were arranged as above; the colours named in the right-hand column show the modifications which they experienced by juxtaposition. Thus, in the first example, the *red* was modified into a colour inclining to *violet*, and the *orange* was modified into *yellow.*

Colours used in the experiment.		*Modification.*
1. Red	inclining to	violet.
Orange	,,	yellow.
2. Red	,,	violet, or less yellow.
Yellow	,,	green, or less red.
3. Red	,,	yellow.
Blue	,,	green.
4. Red	,,	yellow.
Indigo	,,	blue.
5. Red	,,	yellow.
Violet	,,	indigo.
6. Orange	,,	red.
Yellow	,,	bright green, or less red
7. Orange	,,	red.
Green	,,	blue.
8. Orange	,,	yellow, or less brown.
Indigo	,,	blue, or brighter indigo.
9. Orange	,,	yellow, or less brown.
Violet	,,	indigo.
10. Yellow	,,	brilliant orange.
Green	,,	blue.
11. Yellow	,,	orange.
Blue	,,	indigo.
12. Green	,,	yellow.
Blue	,,	indigo.
13. Green	,,	yellow.
Indigo	,,	violet.

(1) De la Loi du Contraste simultané des Couleurs, et de l'Assortiment des objets colorés, considéré d'après cette loi, dans ses rapports avec la Peinture, les Tapisseries des Gobelins, les Tapisseries de Beauvais pour meubles, les Tapis, la Mosaïque, les Vitraux colorés, l'impression des Etoffes, l'Imprimerie, l'Enluminure, la Décoration des Edifices, l'Habillement et l'Horticulture, 8vo., Paris, 1839, with an Atlas of Plates.

In the first volume of the Works of the Cavendish Society, entitled "Chemical Reports and Memoirs," edited by Professor Graham, is a somewhat extended notice of Chevreul's researches, under the title, "Physical Investigations on Dyeing."

Colours used in the experiment.	*Modification.*	
14. Green	„	yellow.
Violet	„	red.
15. Blue	„	green.
Indigo	„	deep violet.
16. Blue	„	green.
Violet	„	red.
17. Indigo	„	blue.
Violet	„	red.

The reciprocal modifications of colour are not limited to the case where the modifying coloured zones are contiguous to one another, for they may be observed even when the zones are separated. For example, take two stripes of the same *blue* paper, and two stripes of the same *green* paper, the blue and green being of the same height of tone. Let the stripes be 4 inches in length, and $\frac{3}{8}$ths of an inch wide. Place them parallel to one another, so that the two central stripes of blue and green are nearly $\frac{1}{2}$ of an inch apart, and the two outer stripes of blue and green each $\frac{1}{4}$ of an inch from the two inner ones. Then, standing at a distance of six paces from the card, the colours will appear modified; the central blue will be of a less green blue than the outer blue; and the central green will be of a green more yellow than the outer green.[1]

All the foregoing phenomena are expressed by M. Chevreul in the following simple law:—"When the eye sees at the same time two colours which are in contact, they will appear as dissimilar as possible." Hence the colour of the stripe O, Fig. 1327, will differ as much as possible from that of the stripe P when the complementary colour of P is added to the colour of O: in like manner the colour of P will differ in the greatest possible degree from the colour of O, when the complementary colour of the latter is added to the colour of P. Consequently, in order to know what the two colours O and P will be when in juxtaposition, it will be sufficient to find the complementary colour of P, and add it to the colour O, and the complementary colour of O, and add it to P. For example, take any one of the above seventeen cases, such as the *green* and *yellow* stripes, the result will be as follows:—*red*, the complementary colour to *green*, on being added to *yellow* makes it incline to *orange;* and *indigo* inclining to *violet*, the complementary colour to *yellow*, makes *green* incline to *blue*. So also with *red* and *blue* stripes; *green*, the complementary colour to *red*, on being added to *blue*, makes it incline towards *green;* and *orange*, the complementary colour to *blue*, on being added to *red*, makes it incline towards *orange*.

It will be evident, that, other things being the same, the modification of the juxtaposed colours will be more marked in proportion to the difference between the complementary colours added to each: for supposing that the complementary colour added to O, Fig. 1327, be identical with it, and that the complementary colour added to P were identical with it also, the modifications of O and P would be confined to a mere augmentation in the intensity of the colour. But we are not acquainted with two perfectly pure colours complementary to each other. All reflected rays of colour transmit not only white light, but also variously coloured rays. It is therefore impossible to name a *red* body and a *green* body, or an *orange* body and a *blue* body, or a body of a *yellow* inclining to *orange* and an *indigo* coloured body, or lastly, a body of a *yellow* inclining to *green* and a *violet* coloured body, reflecting colours that are perfectly pure and complementary to each other, so that their juxtaposition shall merely occasion a simple augmentation of intensity in colour. If, therefore, it be less easy in general to verify the law of contrast with respect to *red* and *green* bodies, or *orange* coloured and *blue* bodies, &c., than with respect to those treated in the seventeen observations already detailed, it will be found that in endeavouring to establish this law for the first-named bodies, their colours will acquire a most remarkable splendour, vivacity, and purity; because, by the law already stated, any object, say of an *orange* colour, reflects *blue* rays just as an object of a *blue* colour reflects *orange* rays. So that when we place a *blue* stripe in contact with one of an *orange* colour, the colours of the two objects in juxtaposition will be mutually purified and rendered more brilliant, whether this arise from the first-named stripe imbibing *blue* from the vicinity of the second, as that again receives *orange* from the vicinity of the *blue* stripe; or whether we assume that the *blue* stripe destroys the effect of the blue rays of the second stripe, as that destroys the effect of the *orange* rays from the *blue* stripe. It may, however, happen that the *blue* appears to incline to *green* or *violet*, and the *orange* to *yellow* or *red;* that is to say, that the modification is not limited to intensity of colour, but extends likewise to the physical composition. If the latter effect be produced, it will be much more feeble than the former; and in looking a certain number of times at the same coloured stripes, the *blue*, which at first appeared more *green*, will soon appear more *violet;* and the *orange*, which at first seemed to be more *yellow*, will soon appear to be more *red*, so that the phenomenon of modification, which depends upon the physical composition of the colour, will not be so constant as those treated of in the seventeen observations.

White is also affected by the presence of colours. If a *coloured* stripe be placed by the side of a *white* one, the latter will appear slightly coloured by the complementary colour of the coloured stripe. Thus, with a *red* and a *white* stripe, *green*, the complementary colour to *red*, blends with the *white*, and the *red* appears to be deeper and more brilliant.

Black and *white*, which may to a certain extent be considered complementary to each other, become, conformably to the law, more different from each other than when seen separately, owing to the effect of the white light reflected by the black, being more

(1) The modifications referred to also take place when the colours are at a considerable distance apart. Thus, we may take leaves of coloured paper, twenty inches in length, and a foot in width, instead of the bands used in the experiments; the two outer leaves are to be placed one yard from the leaves in contact. By such means, it is easy to produce the results to a large audience in a lecture room.

or less destroyed by the light of the white band. By an analogous action, *white* heightens the tone of the colours with which it is brought in juxtaposition.

The phenomena presented by *black*, when exposed to the influence of colours, seem to be owing to the colour with which it is brought in contact acting relatively to the eye, upon the *white* light reflected by the *black* surface, in the same manner as if it were brought in juxtaposition with a *white* surface. Hence, the *black* should be tinged with the complementary tone of the colour touching it; and as the tinge which it assumes is not weakened by so much *white* light, as in the case where the colour is brought in contact with white, it must be so much the more striking. On the other hand, as *white* heightens the tone of colours brought in contact with it, *black*, on the contrary, tends to make them *lighter*. The tone of black must depend, 1. upon the colour added to it; for example, an *orange-coloured red*, an *orange-coloured yellow*, or a *yellowish green*, will brighten it; while *indigo*, even if it does not heighten the tone, will not reduce it. 2. Upon the force or brilliancy of the colour in juxtaposition with it; thus bright colours, as *orange* and *yellow*, tend by their brilliancy to add force to *black;* while *sombre* colours, such as *blue* and *indigo*, do not produce a similar effect.

When *red and black* stripes are made the subject of experiment, *green*, the complementary colour to *red*, blends with *black*, and makes it appear less *reddish*, the *red* becomes more brilliant, and has less of an *orange* or *brown* tone of colour. With *green and black* stripes, *red*, the complementary colour to *green*, blends with *black*, rendering it more *violet* or *reddish*. With *indigo and black*, the *yellow inclining to orange*, the complementary colour to *indigo* blends with *black*, and brightens it considerably; the *indigo* also becomes brighter.

When a great difference is produced by the juxtaposition of two colours, it is rendered appreciable by bringing the same colour successively in contact with the various colours belonging to one group; for example, *red and orange:* on placing a *scarlet* or a *crimson red* in contact with an *orange*, the *red* will acquire a *purple*, and the *orange* a *yellow* tone of colour. *Red and violet.*—Analogous results are obtained in bringing a *scarlet* and *crimson red* in contact with *violet;* the latter will appear to be *bluer*, and the *red* more *yellow*, or less *purple*.

The juxtaposition of coloured stripes shows how difficult it is to fix the *type* of colours. For example: 1. On placing *red* in contact with an *orange-coloured red*, the former appears *purple*, and the latter more *yellow;* but on placing the first-named *red* in contact with a *purple red*, the latter becomes more *blue*, and the former more *yellow* or *orange*, so that the same *red* will be *purple* in one case, and *orange* in the other. 2. On placing *yellow* by the side of an *orange-coloured yellow*, the former appears *greenish*, and the latter more *red:* but on bringing the first-named *yellow* in contact with a *greenish yellow*, the latter will appear *greener*, and the former more *orange*, so that the same colour will in one case incline to *green*, and in another to *orange*. 3. Place *blue* in contact with *greenish blue:* the former will incline to *violet*, and the latter will appear more *yellow*. If the same *blue* be brought in contact with a *violet blue*, the former will incline to *green*, and the latter will appear more *red:* so that the same *blue* will have a *violet* tinge in one case, and a *greenish* hue in the other. Hence it appears, that the simple or primitive colours, *red*, *yellow*, and *blue*, insensibly pass by the effect of juxtaposition into the condition of compound colours, the same *red* becoming *purple* or *orange*, the same *yellow*, *orange*, or *green*, and the same *blue*, *green*, or *violet*.

Chevreul applies the term *simultaneous contrast* to the modification of colour and height of tone experienced by two differently coloured objects when seen simultaneously; and the term *successive contrast* to the phenomena observed when the eyes, after having looked for a certain time at a coloured object, perceive images of a colour complementary to that of the object. The physiological explanation of the successive contrast of colours, is based upon the following proposition by Scherffer, "that if a double impression, of which one is vivid and strong, and the other weak, be produced upon one of the senses, we shall perceive the stronger of the two. This occurs principally when both are of the same kind, or when the powerful action of an object on one of the senses is followed by another of the same nature, but infinitely weaker or less violent." To illustrate this, let us look for some time at a small *white* square, placed upon a *black* ground. On ceasing to look at this, and turning the eye upon a *black* ground, we perceive the image of a square, equal in extent to the *white* square, but instead of being *lighter* than the ground, it will be *darker*. The explanation is, that the part of the retina on which the *white* light of the square acted at the first part of the experiment, is more fatigued than the remainder of the retina, which has only received a faint impression from the faint rays reflected by the *black* ground: the eye then being fixed upon the *black* ground during the latter part of the experiment, the weak light of this ground acts more strongly upon that part of the retina which is still unexhausted, than upon that which has already been fatigued; and hence arises the image of the *black* square seen by that portion of the eye.

If we look for some time upon a small *blue* square on a *white* ground and turning the eye away from the square fix it on the *white* ground, we see the image of an *orange* square. The explanation is, that the part of the retina on which the *blue* light of the square has acted in the first case, being more fatigued by this colour than the rest of the retina, it happens in the latter part of the experiment, that the retina which is fatigued by the *blue*, is consequently disposed to receive a stronger impression from *orange*, the complementary colour of *blue*.

It appears, then, that in cases of successive contrast, accidental colours arise from fatigue of the eye: but Chevreul does not admit this to apply to

cases of simultaneous contrast; for in arranging the coloured stripes, as in Fig. 1327, as soon as we succeed in seeing all four together, the colours may be observed to be modified before the least fatigue is experienced by the eye, although it frequently requires several seconds before the modifications can be perfectly recognised. But the time thus employed appears to be as necessary as that which we give to each of our senses, whenever we wish to give an exact account of the perception of a sensation affecting them. Time seems also to be required, on account of the influence of white light, reflected by the surface modified, and which is sometimes strong enough to weaken the result of the modification, and it is only when the influence of this white light begins to decline, that the accidental colours of simultaneous contrast are favourably seen. It is further owing to this cause that *grey* and *black* surfaces, contiguous to the surfaces of very bright light colours, as *blue*, *red*, and *yellow*, are modified more than a white surface would be by their vicinity.

M. Chevreul does not pretend to reduce to theory the beautiful and important phenomena which he has so skilfully and industriously brought together from his own labours, and from the labours of others. He wishes to express the general fact, "that when the eye is struck at once by two colours, which it views with some degree of attention, the analogous character of these colours acts less powerfully upon the optic nerve than the heterogeneous; or in other words, the eye evinces less sensibility in catching the analogies, than the differences of the colours, and this without our being able, generally speaking, to say that the organ is fatigued." It is also shown "that two colours seen distinctly and simultaneously are mutually modified, independently of their respective extent, even when they are not in contact, and when there is no ground for attributing their modifications to a fatigue of the eye."

Some objections may perhaps be made to the use of the term *simultaneous*, on the ground that the distinct vision of two separate colours is, in fact, successive; for it is not possible to fix the eye steadily upon two colours at the same instant; and when we fancy we succeed in doing so, the eye is in fact passing rapidly from one to the other; in which case, the modifications of colours by juxtaposition is a purely physiological effect, and the theory of Scherffer will apply. The effects on the mind are, however, the same as if the contrasts were really simultaneous; and they are now so well understood, that it is quite easy to determine beforehand the exact effect which any given combination of colours will produce. This is one of the valuable results of the inquiry, and it is gratifying to know, that if M. Chevreul has not succeeded in framing a satisfactory theory of complementary colours, he has, at least, established a rule or law of an eminently practical character. We will give a few of its applications.

Suppose a painter to have delineated two stripes in a picture, a *red* stripe and a *blue* stripe in contact; the phenomena of the contrast of two colours in juxtaposition would occur, unless the painter had taken care to sustain the *red* contiguous to the *blue* stripe by *blue*, and the *blue* stripe by placing *red* or *violet* near the *red* stripe. A weaver having to imitate the two stripes, ignorant of the law of the contrast of colours, will select his wools or silks of only one *blue* and one *red*, and thus bring about the phenomena of contrast which the painter avoided by an ingenious artifice. Or if the painter had not blended the colours on their contiguous borders, they would have contrasted. Now if the weaver, ignorant of the law of this phenomenon, and attempting to imitate his model, were to blend *yellow* or *orange* with the *red*, and *yellow* or *green* with the *blue* in the parts of the stripes that came in contact, the contrast would be more or less exaggerated; because the weaver attempted to imitate the effect of homogeneous colours produced by the picture, by working with homogeneous colours.

Let a paper, Fig. 1328, divided into 10 equal zones, be first painted with a uniform tone of any colour, as with Indian ink: let the zones 2 to 10 receive a second wash of the same uniform tone; let the zones 3 to 10 receive a third, and so on until 10 zones be procured, which gradually increase in depth of tone, proceeding from the first onward. The remarkable part of the phenomenon is, that each zone will present at least two shades, owing to the contrast produced by contiguity; for instance, in beginning from the first the border $b\,b$ of this zone, contiguous to the border $a'\,a$ of zone 2, will appear lighter than the border $a\,a$; and consequently two shades will be presented in zone 1, and the same in the others. But it is possible that a larger number may be distinguished, especially in the intermediate zones between 2 and 9, provided they are of sufficient breadth, and this is owing to the borders $a^1\,a^1\,a^2\,a^2$ being lighter, and the borders b^1 b^1 b^2 b^2 darker than the general tone of the zone, when, by reason of contrast, the middle of the zones, being less affected than the borders, will present a third tone of colour. It is evident that the three tones, or the two tones as the case may be, presented by the zone,

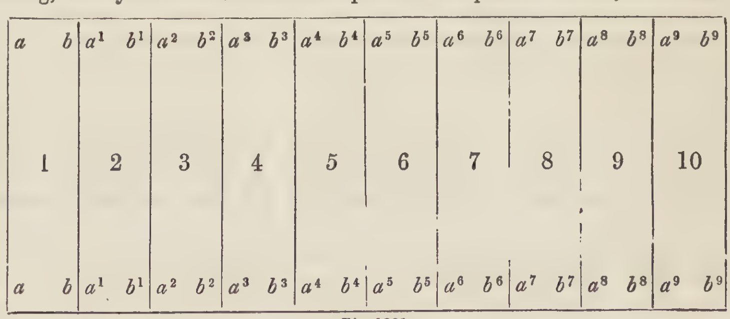


Fig. 1328.

will not terminate abruptly, but blend into one another. Now, if a weaver were to copy this figure, and were not acquainted with the effect of contrast of contiguous zones, he would exaggerate the effect in his work, using probably at least twenty shades of the same colour, instead of the ten.

"I have frequently," says M. Chevreul, "been appealed to as an arbiter in cases where persons having given to be printed various woollen stuffs for furniture, and ladies' cloaks, and have had disputes with the printer on the subject of the patterns, which were not of the colour intended. I have often found that these complaints depended upon the effect of the contrast of the colour of the designs with that of the ground, and that if the printer were reprehensible, it was not for having printed a different colour from the one required, but for not having foreseen the effect that would result from the contrast of colours, one of which was to serve as a ground for another." For example, when *black* patterns are printed upon *red, crimson,* or *amaranth* grounds, they appear *green,* the complementary to the ground appearing on the black. For the same reason, *black* when printed on *violet* stuffs, or on *dark green,* loses all its force. In order to prove that the designs which do not appear black, are really black, all that is necessary is to cut a piece of white paper so as to cover the ground, and show only the pattern. Similar difficulties arise in manufactories of paper-hangings, when it is required to produce a design of a slightly *yellowish grey* upon a *green* ground; the designs, although actually grey, appear to be *pink,* owing to the complementary colour of the ground. If printed on *rose*-coloured ground, they appear *green* for the same reason. In printing letters on coloured paper, the ground should always be complementary to the colour of the ink. Thus a *violet*-coloured ink must be used for *yellow* paper; and *yellow* ink on a *violet*-coloured paper; *red* ink on *green* paper, and *green* ink on *red* paper; *orange*-coloured ink on *blue* paper, and *blue* ink on *orange*-coloured paper.

The upholsterer and house decorator, in the assortment of stuffs with fancy woods for making sofas, easy chairs, &c., must attend to the law of simultaneous contrast. Thus, *violet* or *blue* stuffs should be selected for *yellow* woods, such as orange wood, the root of the ash, &c., and *green* or *yellow* stuffs for *red* woods, like mahogany. The colour of the stuff must be as different as possible from that of the wood. A crimson stuff is one of the best wearing colours, and hence it is often used with mahogany. The bad effect of this arrangement may be diminished by placing a broad *green,* or *black* border, a cord, or a printed band, between the *crimson* and the *mahogany.* It is not uncommon to border *crimson* with a *gold* cord, or band, fastened on with gold-headed nails; and although these borders are not complementary, the effect is brilliant. There is one combination which ought never to be made, viz. *yellowish-red* as *scarlet, flame*-coloured, or *light red* stuffs with mahogany; since their brightness deprives the wood of its characteristic red colour, and makes it resemble oak or walnut. Decorative painters fall into the fault of using *pink* or a light *amaranth* for the hangings of boxes in a theatre, the effect of which is to give a *greenish* tinge to the complexion. In the choice of patterns for damasks, for furniture, opposition of the grounds with the predominating colour of the designs upon them, is too often disregarded. For instance, where a wreath of flowers is to be represented on a *crimson* ground, the greater part ought to be composed of *blue, yellow,* and *white* flowers; if *red* flowers are introduced, they should border on *orange* rather than *purple;* while *green* leaves laid directly on the ground conduce considerably to the beauty of the whole; where the ground is *green* or *dead-leaf,* the predominating flowers ought on the contrary to be *pink* and *red.*

Not only may the pattern designer, whether for figured stuffs, silks, carpets, &c. derive much assistance from the study of these details, but also the artist, the glass stainer, all those, in short, who have to deal with colour. Even the florist may enhance the charms of his art by attention to the law of simultaneous contrasts. "Nothing is more common," says M. Chevreul, "than a defect of proportion observed in the manner in which flowers of the same colour are made to recur in a garden. At one time the eye sees nothing but blue or white, at another it is dazzled by yellow scattered around in profusion: the evil effect of a predominating colour may be further augmented, when the flowers are of approximating but still different shades of colour. For instance, in the spring we meet with the jonquil of a brilliant yellow, side by side with the pale yellow of the narcissus; in the autumn, the Indian pink may be seen next to the China rose and the aster, and dahlias of different red grouped together, &c." "The principal rule to be observed in the arrangement of flowers is to place the *blue* next to the *orange,* and the *violet* next to the *yellow,* whilst *red* and *pink* flowers are never seen to greater advantage than when surrounded by *verdure* and by *white* flowers: the latter may also be advantageously dispersed among groups formed of *blue* and *orange* and of *violet* and *yellow* flowers. For, although a clump of *white* flowers may produce but little effect when seen apart, it cannot be denied that the same flowers must be considered as indispensable to the adornment of a garden when they are seen suitably distributed amongst groups of flowers, whose colours have been assorted according to the law of contrast. There are periods of the horticultural year, when white flowers are not sufficiently abundant to enable us to derive the greatest possible advantage from the flora of our gardens. It should be remarked that plants whose flowers are to produce a contrast should be of the same size, and that in many cases the colour of the sand or gravel composing the ground of the walks or beds of a garden may be made to conduce to the general effect."

The application of the law to the colours of dress requires some notice. It is a matter of common observation, that a uniform composed of cloths of different colours looks well much longer, although

worn, than one of only a single colour, even when the cloth of the latter is identical with one of those composing the former. The law of contrast perfectly explains the reason: if we suppose a uniform to be made of cloth of two colours, the one complementary of the other, as *red* and *green*, *orange* and *blue*, *yellow* and *violet*, we shall find that the effect will be most excellent from their mutually heightening one another; and supposing, further, that they are of equal stability, they will present greater advantages, and appear good in spite of atmospheric agents, longer than any other binary combination of colours. In a blue and yellow uniform, the blue gives to the yellow an orange tint, which greatly heightens its effect, notwithstanding its tendency, as a dark colour, to make another colour appear lighter; the yellow imparts in its turn a violet tinge to the blue, which considerably improves its appearance, and if the blue had an unpleasant greenish tinge, it would be neutralized by the yellow. On the other hand, stains will always be less visible on a dress of different colours than on one composed only of a single colour, since there exists in general a greater contrast among the various parts of the first-named dress than between the stain and the adjacent parts; this difference renders the effect of the stain less apparent to the eye. For the same reason, a coat, waistcoat, and trowsers, of the same colour can only be worn to advantage together when all are new; for as soon as one of them loses its freshness from having been worn longer than the others, the difference will increase by contrast. For instance, a pair of new black trowsers, worn with a waistcoat of the same colour, which is old and a little rusty, will make the tinge of the latter appear more conspicuous, at the same time that the black of the trowsers will appear more brilliant. White or even light grey trowsers would produce a contrary effect. We see from this, how advantageous it is to let soldiers have winter trowsers of a different colour from that of the clothes which they wear during the rest of the year; and we can further understand the advantage there is in wearing white trowsers with a blue, or indeed, generally speaking, with any dark coloured coat.

The Great Exhibition afforded abundant evidence of the superior taste of the foreign decorative artists as compared with that of our own exhibitors. Where, for example, the goods were each of a single lively colour, variety was produced by means of figured canopies and draperies: where, on the contrary, the goods were of light materials, such as muslins, and were covered with floral designs, plain-coloured canopies and fittings, sometimes of rich materials, were employed: in some cases the colours were concentrated and brought to a focus by the judicious introduction of a well-assorted pile of plain merinos and crapes of pure colours, the surfaces of which having no lustre, are seen in their proper colours. In an assortment of *black* silks the sombre effect of the black was obviated by the introduction of a few pieces of *orange* coloured silk. Even such articles as feather brushes were coloured and arranged with artistic skill. In some, the outside feathers were *red*, and those in the centre *green;* in others, the outside feathers were *green*, and the middle ones *red;* in others, *blue* feathers harmonized with *orange;* and so on. In the British department the combinations of colour were often crude and unpleasant, and the contrasts positively painful; whereas, in the foreign departments, harsh and inharmonious contrasts were avoided, as Mrs. Merrifield observes, by interposing rich figured or striped goods of different, but friendly colours, so as to conduct the eye agreeably and gradually from one contrasting colour to the other.[1]

The lady just referred to has made some excellent remarks on the various pattern designs as they came under her notice in the Great Exhibition. We will conclude this article with a few brief extracts. After noticing at some length the coloured patterns of the carpets, she refers to those "libels on pictures executed in Berlin wool," and justly remarks that, "if half the time that young ladies devote to these useless labours were devoted to the acquirement of a knowledge of the principles which govern the harmony of colours,—a kind of knowledge which is very easily attained,—the good effects would soon be apparent, not only in the more appropriate choice of subjects on which to display their skill in needlework, but in better and more tasteful work applicable to domestic purposes." The proper subjects for this kind of work are flowers, birds, arabesques, and other objects which admit of the introduction of lively colours. Subjects which involve the combination of tints, requiring nice gradations of colour and a careful attention to light and shade, such as occur in figure-subjects, should be avoided.

The *papier-mâché* and japanned goods presented but few examples of good taste in colouring. "In these, the glitter of metallic colours is too frequently mistaken for richness, and violent contrasts for harmony. The artist seems to run riot in the riches of his palette, and to endeavour to dazzle if he fails to please. In speaking of the want of harmony in the colouring of carpets, due allowance has been made for mechanical defects, which render the adoption of certain designs a matter of some difficulty; but none of these defects can be imputed to the painting of *papier-mâché* works. With an almost unlimited scale of colour, and obedient materials, which are capable of producing the richest and most harmonious effects of colour, these works, by the bad taste too often perceptible in their decorations, contrast disadvantageously with the Indian articles of the same nature, in imitation of which they were originally manufactured.

"The Indian principle of ornamentation deserves as much attention as the material, and the examples of the tiles and mosaic pavements may be adduced as instances of the advantage attending the study of the principle of decoration adopted in national manufactures, as well as the materials employed. The same abruptness and crudity of colouring which are per-

(1) "Essay on the Harmony of Colours as exemplified in the Exhibition." This Essay has already been referred to in our Introductory Essay, p. xlviii.

ceptible in the English carpets, are also too often visible in the printed table-covers, the dyed sheep-skins, the designs for silk handkerchiefs, and the furniture chintzes and damasks. In many of the latter the designs are very beautiful, but the colours are frequently ill-assorted, as well as harsh, from the extreme *strength*, and in some cases *blackness*, of the shadow colour, especially when contrasted, as frequently happens with regard to furniture-prints, with a white ground. Although, as has been justly remarked, the British manufacturers are inferior in colouring, and frequently in design, to the continental exhibitors in decorative art—for under this term we must include those elaborately ornamented carpets, dress, and furniture fabrics, exhibited in the Crystal Palace—there is evidently an improvement upon former designs; and when the subject of colour has received the attention which it deserves, we may confidently reckon on a still greater improvement. The elegant designs, and the harmonious colouring of the French and Italians in their art-manufactures, has been the subject of general commendation; but neither of these nations acquired their good taste in design and colour in a day, or without study. In former times, it is well known, the best Italian artists did not think it beneath them to make designs for art-manufactures; hence the good taste of the Italians in the lower branches of art. The French have had schools of design for more than a century; and in consequence of the attention paid in these schools to the harmony of colours, their art-manufactures exhibit a better and more harmonious style of colouring than many of their works of the higher classes of art,—a convincing proof of the success attending the study of the subject, and the advantages to be derived from the contemplation of good examples. When the British manufacturers study colour with the same earnestness as the British artists have done, the happy results will be visible in their productions; and not until then can they successfully compete in the decorative arts with their continental neighbours."

LIGHTHOUSE. An elevated structure erected on a rocky or dangerous shore, for the purpose of raising to a conspicuous height the warning beacon which shall repel the mariner, and enable him to avoid destruction. The erection of a lighthouse or beacon is an evident duty of common humanity, and it appears to have suggested itself as such among the nations of antiquity. Beacon fires were kindled at an early period along the most frequented coasts, flaming forth perhaps from the summit of a temple dedicated to the gods, and where sacrifices were being offered to appease the genius of the storm. There are few distinct early evidences of the erection of lighthouses as such, although there are allusions to the subject of beacon lights for the guidance of the mariner in the writings of Homer and others. But it is a matter of certainty that in the reign of Ptolemy Philadelphus, about 300 years before the Christian era, there was erected at Alexandria the celebrated Pharos, or beacon tower, which ranked among the ancients as one of the seven wonders of the world. Sostratus, the architect, is recorded to have built this structure in a wonderful manner, of many storeys of white stone on a rock, forming the promontory of the island of Pharos, and to have dedicated it "to the gods, the saviours, for the benefit of seamen." Pliny says that this tower cost a sum equal to about 390,000*l*. The different descriptions of this celebrated lighthouse leave it a matter of uncertainty whether the beacon displayed the flickering and rude light of a common fire, or whether a more perfect mode of illumination was employed. It is stated to have been 400 feet high, and to have sent its light to a distance of 40 miles, both of which are manifest exaggerations. Contemporary with the erection of the Pharos of Alexandria was that of the Colossus of Rhodes, by many supposed to have been the bearer of an important beacon-fire. This gigantic statue of brass, between whose legs vessels could sail into the harbour which it spanned, was partly demolished by an earthquake seventy years after it was formed, and so late as the year 672 of our era; the brass which composed it was sold to a Jewish merchant of Edessa, by the Saracens, who received for it a sum said to equal 36,000*l*.

The traditionary history of Ireland makes mention of the Tower of Coruña, as a lighthouse erected for the use of the Irish in their early intercourse with Spain. Other ancient lights are spoken of, but our knowledge of them is neither accurate nor extensive. Many of them appear to have been merely pots of fire raised on poles, or placed on the summit of rocks, the greater number being described as existing on the shores of the Mediterranean Sea.

Among modern lighthouses, the earliest having any pretensions to architectural elegance is the Tour de Corduan, at the mouth of the Garonne. This is 197 feet high, and consists of a number of galleries, surmounting an immense platform of solid masonry. The galleries gradually diminish in diameter, and terminate in a conical tower, and lantern. In the latter a wood fire first formed the beacon, then a coal fire, and at last lamps and reflectors. The celebrated apparatus of Fresnel was adjusted in this lighthouse in 1822.

The history of the lighthouses successively built on the Eddystone rocks is full of interest, but can be only glanced at here. Those rocks are situated 14 miles from the port of Plymouth, and 9½ miles from a point of land called Ram-Head, on the coast of Cornwall. Many rich vessels were formerly lost on these dangerous rocks, which lie exposed to the heavy seas from the south-western points of the compass, and from their peculiar conformation increase the swell to a frightful extent, often sending up the waves to a height of thirty or forty feet. The whole range of these rocks is covered by the tide at high water, so that the difficulty of commencing and carrying on the structure between the tides was immense. It was first attempted by Henry Winstanley, who after four years' labour, working only in the summer season, constructed a lighthouse of timber. This

work was commenced in 1696,—it had advanced sufficiently to exhibit a light in 1698, but it was not completed till 1700. The instability of the structure was unhappily proved, three years later, by the destruction of the lighthouse with its engineer and workmen, engaged there on repairs during a violent storm, 26th November, 1703. Another lighthouse was commenced in 1706, by John Rudyerd,—the light was shown in 1708, and it continued to be displayed for 47 years, when the lighthouse was accidentally destroyed by fire. This second edifice was also of timber, but remarkably well constructed and simple in form, 92 feet high and 23 feet diameter at the base. The foundation was of oak-timber and stone, in alternate layers, secured with cramps of iron, the whole being fastened with bolts or branches of iron to the rock.

The value of a light on the Eddystone rocks had been by this time fully proved, and no time was lost in endeavouring to supply the place of Rudyerd's structure. Happily the work was entrusted to John Smeaton, whose name is now identified with the undertaking, the more emphatically, because of his own elaborate and interesting narrative of the whole proceeding. The first stone was laid June 12, 1757, and the last August 24th, 1759. This beautiful structure is entirely of stone, and the foundation is most ingeniously secured by a system of dove-tailing, cementing, wedging, and bolting together with stone joggles and oaken trenails, which connects, and makes it one with the natural rock, the sloping surface of which had been cut into steps or terraces to receive the foundation stones. Fig. 1329 is a plan of the *house-rock*, or that on which the house was built, as prepared for the stone work. The first course is seen occupying the lowest step, and secured with its trenails and wedges: it is laid within a border of solid rock, and is held fast in every direction.

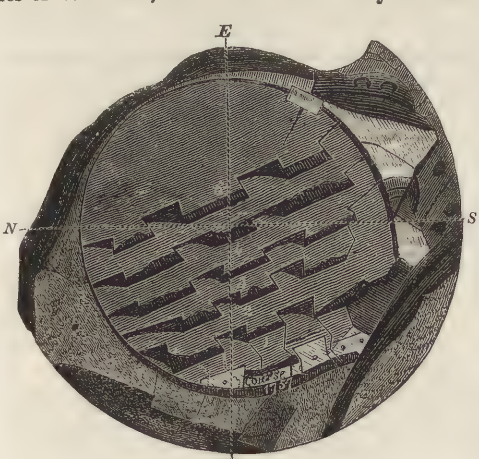


Fig. 1329. PLAN OF THE HOUSE-ROCK, AS PREPARED BY SMEATON.

The figures 1, 2, 3, 4, 5, 6, mark the level steps or platforms into which the rock was cut for the different courses. Fig. 1330 shows the appearance of the rock when these platforms had been filled with their respective courses, and the whole work brought to a level with the reduced rock. When this was effected, and means no longer existed of securing the stones to the rock, Smeaton devised the expedient of bolting the courses together, by cutting a hole a foot

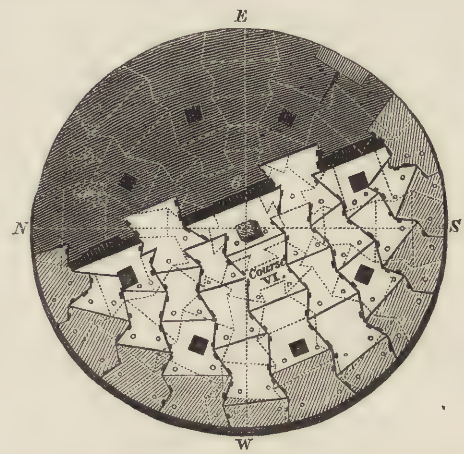


Fig. 1330. THE ROCK BROUGHT TO A LEVEL.

square through the centre stone of each course, and fitting into it a plug of strong hard marble, which should be long enough to enter a similar hole in the centre stone of the next course. These centre stones were dove-tailed into the surrounding stones, and no force of the sea acting horizontally could affect the masses thus secured together. Besides the central *plug-joggle* (as Smeaton calls it), there were eight other joggle or plug-holes in the circumference, not only in that part occupied by the stone course, but also in the solid rock. The courses thus laid and ingeniously secured formed the whole of the foundation work: this was severely tried during the time of its erection, and also in the winter following, but stood the utmost force of the waves, and became like the solid rock itself. The building was next carried up in a solid form, as high as there was any reason to expect the heaviest strokes of the sea to act upon it, namely to 35 feet 4 inches above the base. At this height the rooms were commenced, the walls of which were made of single blocks of stone, so shaped that sixteen blocks formed a complete circle, or stout wall 26 inches thick. Fig. 1331 shows a part of the wall thus constructed: *f* is a marble plug the size of a common brick, let half its thickness into the middle of the stone, so that the next course above, breaking joint upon the middle of this, according to the dotted line *g g*, half the plug would enter the one and half the other of the two stones which met above it. Thus every stone of the succeeding course was secured between steady pins at each end. The black lines *h i* mark the joints of the course, in the centre of which is a lozenge-shaped groove filled with a joint stone, over

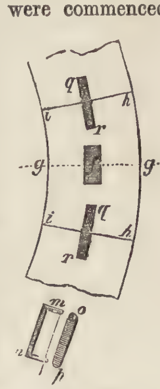


Fig. 1331.

which, for greater security, was fitted an iron cramp, the shape of which is shown at *m n*: *o p* marks its appearance as fitted in its place. Holes were bored in the stone at *q r* to receive the round-shanks of the cramp, and rectangular cavities sunk to bury the flat part of the cramp. The mode of inserting these cramps was to make each cramp hot, then to place it in the holes, which had previously had a spoonful of oil poured into each. The ebullition of the oil made the whole cavity unctuous, and assisted the perfect filling up of every crevice with the molten lead, which was next poured in until the cramp was completely covered. The courses on which the floors of the rooms rested were further strengthened by having a groove cut in their upper surface, and a chain introduced as shown at Fig. 1332: the groove was then filled up with melted lead; thus the building was hooped or girdled together at the parts where danger might have arisen from lateral pressure. In this way the walls were carried up, forming first the lower and the upper store-room, above them the kitchen, and then the bedroom, above which rose the lantern with its railed balcony, cupola, and gilt ball.

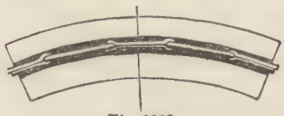


Fig. 1332.

This noble structure was commenced on the 12th June, 1757, and completed on the 24th August, 1759.[1] The main column of the lighthouse contains forty-six courses of stone, and reaches the height of nearly 70 feet. The diameter at the level of the first entire course is 26 feet: the diameter under the balcony is 16 feet. In addition to the windows for the lantern, 10 other windows exist in the edifice, 4 each in the kitchen and bedroom, and 2 in the store-room, but these are small, and capable of being entirely closed and made level with the outer wall of the building, by means of storm-shutters.

The completion of the Eddystone lighthouse was followed by a series of storms which effectually tried the strength of the building, and also produced the greatest terror in the minds of the first light-keepers. Smeaton watched the edifice with the greatest pleasure and interest, and when viewing it with his telescope from the garrison at Plymouth, after a great storm, he found to his astonishment that at intervals of a minute, and sometimes two or three, when a combination happened to produce an overgrown wave, "it would strike the rock and the building conjointly, and fly up in a white column, enwrapping it like a sheet, rising at least to double the height of the house, and totally intercepting it from sight; and this appearance being momentary both as to its rising and falling, one was enabled to judge of the comparative height very nearly, by the comparative spaces alternately occupied by the house and the column of water in the field of the telescope." After the occurrence of many such storms without the least injury to the building, the safety of the Eddystone was never doubted, and light-keepers even became attached to the spot and reluctant to leave it. In fact it was a much safer place during violent gales than most parts of the neighbouring shore. The lights first displayed were merely tallow candles: Argand burners, and paraboloidal reflectors were substituted in 1807.

(1) Smeaton's account of this noble work was not published until the leisure consequent on his retirement from the duties of a useful and laborious life enabled him to collect and prepare the materials required. In 1791 he published a folio volume, entitled, "A Narrative of the Building and a Description of the Construction of the Edystone Lighthouse with stone: to which is subjoined an Appendix, giving some account of the Lighthouse on the Spurn Point, built upon a sand."

The lighthouses on the coast of Scotland are deservedly celebrated. Systematic efforts for lighting this extensive and dangerous coast were not commenced until 1786, namely, twenty-seven years after the completion of the Eddystone. Four lighthouses were all that had been at first contemplated; but when these were erected, one on Kinnaird Head in Aberdeenshire, one on the Orkney Islands, one on the Harris Isles, and one at the Mull of Kintyre in Argyleshire, their importance to navigation became so evident, that great efforts were made on the part of the shipping interest to obtain others. In the course of time, lighthouses, or the means of exhibiting lights, were erected upon many promontories of the main land, as well as upon islands and reefs lying off the coast of Scotland, including the Isle of Man.

The most celebrated of the Scottish lighthouses, and that which may be taken as the representative of the whole, is that on the Bell Rock, a dangerous reef at the entrance of the Frith of Forth, also known as the Inch Cape Rock, and as such celebrated in Southey's ballad of "Sir Ralph the Rover." This reef is frequently under water to the depth of from twelve to fifteen feet, therefore the erection of a lighthouse was a work of peculiar difficulty. Robert Stevenson, however, examined the rock, and reported that it was practicable, and that a work of stone similar to that of the Eddystone might be erected there. The Bell Rock is twelve miles from the shore, and lies directly in the fair way to the Friths of Forth and Tay; therefore it is most dangerously situated for vessels, and has in fact been a most fatal reef, destroying many a noble ship and valuable freight. The first step towards Stevenson's great work, was to moor a fishing vessel off the Bell Rock, at the distance of about two miles, to serve the double purpose of a floating light, and a tender for the workmen employed in the building. The vessel was rigged with three masts, on each of which a lantern was hoisted; she was also manned with a crew consisting of a master, eight seamen, and a boy.

The first actual work on the rock consisted in boring a sufficient number of holes to receive the ends of beams for the support of a wooden beacon or workshop, and temporary residence for the workmen. This was a most difficult operation, for in addition to the hardness of the rock, which blunted the tools and required the constant help of a smith with his forge, there was the precarious nature of the work, owing to the short time the men could be on the rock, and even then frequently knee-deep in water. The rowing

backwards and forwards from the floating light at every tide was found very laborious, and when the sea was rough it was impossible to leave the moored vessel, the putting out of a boat being almost certain destruction. The temporary building of timber being finished, and an extensive excavation made, at immense labour, in that part of the rock designed as the site of the permanent structure, the nature of the subsequent daily operations was as follows:—The workmen landed on the rock at low water, and immediately began to bale out the water from the foundation pit, while the pumps were also kept in action. The work was proceeded with on the higher parts of the foundation as the water left them. The pumps being placed diagonally, about twenty men were employed to work each pump; and thus this great body of water, extending over a circular area of 42 feet diameter, and of the average depth of 2 feet, could be drawn off in half an hour. The men then proceeded for two hours and a half to level the foundation with their picks, some of the sailors being employed to clear away the chips, and convey the iron tools to and from the smith's forges, which were flaming on the temporary building above, while the anvils thundered with the rebounding noise of their wooden supports. The tools were thus continually sharpened, and the work was carried on with urgent speed, until the sea again broke in and overflowed the pit, when the party returned in boats to the tender. The perils and narrow escapes of this little band of determined men are described in a highly interesting manner by Mr. Stevenson in his account of this undertaking, published at the expense of the Lighthouse Board in 1824.[1]

The foundation stone of the tower was laid on the 10th July, 1808, at the depth of 16 feet below the high water of spring tides. It was square in form, and contained about 20 cubic feet. The first continuous course was then landed on the rock and laid down. The kind and quantity of work in this one course alone are thus enumerated by Mr. Stevenson:—The course was only one foot in thickness, yet it contained 508 cubic feet of granite in outward casing; 876 cubic feet of Mylnefield stone in the hearting; 104 tons of solid contents; 132 superficial feet of hewing in the face work; 4,519 superficial feet of hewing in the beds, joints, and joggles; 420 lineal feet boring of trenail holes; 378 feet lineal cutting for wedges; 246 oaken trenails; 378 oak wedges in pairs. Three seasons were occupied in preparing the rock, in laying the foundation, and carrying up the solid part to the height of 30 feet. So short was the time actually obtained for labour on the rock, that 265 hours was the total amount during the second season, and of these only 80 were employed in actual building work. The winter months of each season were, however, diligently employed on shore, in preparing the stones and accurately fitting them, so as to shorten as much as possible the labour on the rock. At the commencement of the next season the workmen took permanent possession of the rock, and the work proceeded rapidly. As the tower rose in height the action of the sea upon it was regarded with much interest. In a heavy surf the effect was grand and magnificent, but not calculated to excite alarm. In the early part of July 1810, great interest was created by a visit of Smeaton's daughter to the rock. The building was then nearly finished, and she came to view it in a boat which Mr. Stevenson had named the "Smeaton" in honour of her father. The 29th day of the same month was one of great rejoicing on the rock, for then the last stone was landed. It was laid in its place on the next day by Mr. Stevenson with the following prayer,—"May the Great Architect of the Universe, under whose blessing this perilous work has prospered, preserve it as a guide to the mariner!"

The remaining arrangements and interior details were so far completed during the year that the light was advertised to the public to be exhibited every night from 1st of February, 1811. The advertisement minutely described the nature of the light, stating, "The light will be from oil, with reflectors placed at the height of about 108 feet above the medium level of the sea. To distinguish this light from others on the coast, it is made to revolve horizontally, and to exhibit a bright light of the natural appearance, and a red-coloured light alternately, both respectively attaining their greatest strength, or most luminous effect, in the space of every 4 minutes; during that period the bright light will, to a distant observer, appear like a star of the first magnitude, which after attaining its full strength is gradually eclipsed to total darkness, and is succeeded by the red-coloured light, which in like manner increases to full strength, and again diminishes and disappears. The coloured light, however, being less powerful, may not be seen for a time after the bright light is observed. During the continuance of foggy weather and showers of snow, a bell will be tolled by machinery night and day, at intervals of half a minute."

The Bell Rock Lighthouse was now complete, and its appearance was noble and pleasing to the eye. (See Vignette to vol. i. of this work.) The form is circular, the tower is 100 feet high, and the whole structure, including the light-room, is 115 feet. The form of the light-room is octagonal, 12 feet across, and 15 feet high. It is framed with cast iron and glazed with plate glass. A dome rises above it terminating in a ball. The diameter of the tower at the base is 42 feet, at the top 13 feet. The entrance door is 30 feet from the base, and the ascent to it is by a trap ladder. Visitors are generally hoisted up in a chair by a movable crane. The cost of the erection of the Bell Rock Lighthouse was 61,331*l.* 9*s.* 2*d.*

Another work of great labour and difficulty was the erection of a lighthouse of stone on the Skerryvore Rocks, which lie about twelve miles W.S.W. of the seaward point of the Isle of Tyree, in Argyll-

(1) "An Account of the Bell Rock Lighthouse, including the details of the erection and peculiar structure of that edifice. To which is prefixed a Historical View of the Institution and Progress of the Northern Lighthouses. Drawn up by desire of the Commissioners of the Northern Lighthouses, by Robert Stevenson, C.E." 4to. Edinburgh, 1824.

shire, and were formerly the scene of numerous fatal shipwrecks. The operations were commenced in 1838, the architect being Alan Stevenson, son of Robert Stevenson, and engineer to the Board of Northern Lighthouses. The difficulties, dangers, and successful issue of this important undertaking are described by the engineer himself.[1]

The construction of the lighthouse itself had no very remarkable points of difference from the works of Smeaton and the elder Stevenson; we shall therefore only borrow from this narrative a sketch of a temporary barrack which formed the dwelling of the engineer and workmen on the rock, during the progress of the permanent structure. Fig. 1333 will give a good idea of the nature of this singular dwelling.

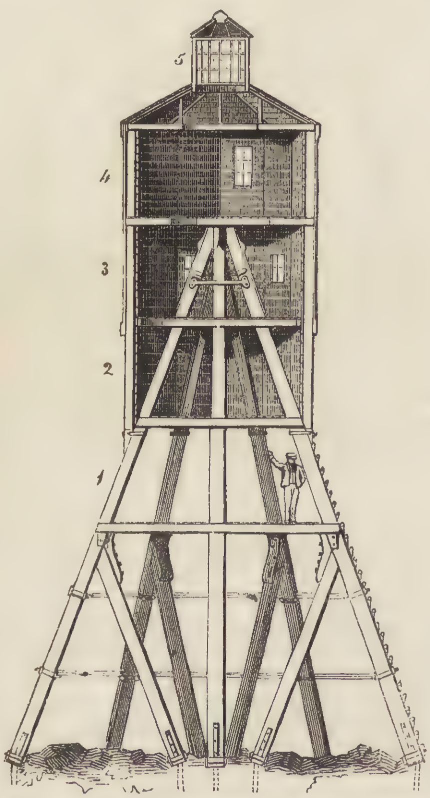


Fig 1333. TEMPORARY BARRACK USED IN THE ERECTION OF THE SKERRYVORE LIGHTHOUSE.

1. Store for Coals.
2. Kitchen and provision store.
3. Engineer's and foreman's apartments.
4. Barrack room for workmen.
5. Ventilating lantern.

"Immediately under the wooden tower," says Mr. Stevenson, "was an open gallery, the floor of which was removed at the end of each season, so as to allow free space for the passage of the sea during the storms of winter, but on which, during summer, we kept the stock of coals, the tool chests, the beef and beer casks, and other smaller materials which we could not, even at that season, safely leave on the rock itself. Next came the kitchen and provision store, a six-sided apartment about 12 feet in diameter, and somewhat more than 7 feet high, in which small space, curtailed as it was by the seven beams which passed through it, stood a *caboose*, capable of cooking for forty men, and various cupboards and lockers lined with tin, for holding the biscuits, meal, flour, barley, and other things needful for the sustenance of the human frame. That apartment, for protection against fire, was coated partly with tin, and partly with sheet lead, which latter, although not in all respects the most desirable material to come in contact with that element, was found to be the only one which we could in some parts conveniently apply." The next storey was divided into two apartments, which together consisted of a twelve-sided narrow space, twisted around a centre pyramid whose bevelled faces formed their sloping walls on one side. "The half of that space," says Mr. Stevenson, "constituted my apartment, which I think would be generally pronounced not over commodious; and when it is added that it contained my bed, desk, chair and table, and a stock of groceries, it will be readily imagined I had little room to spare for myself. So much attention was paid to economy of space, that the recesses of the pyramid formed by the meeting of the beams were boarded over and made into cupboards; while my *cot*, or framed hammock (which during the night rested upon brackets which could be folded close to the wall when not required) was, during the day, hoisted by pulleys to the roof of the apartment, so as to leave me as much space to move about as a prisoner could expect. The cornice of the apartment consisted of a narrow shelf adorned with books, which I found very needful helps to solitary life. The highest apartment was also twelve-sided, surmounted by a pyramidal roof, and a small six-sided lantern or ventilator, and was lined round the sides with four tiers of berths, capable of accommodating thirty people."

The instances already given will be sufficient to show the nature of the operations carried on, when a lighthouse is to be built upon the solid rock; but there is another class of difficulties to be encountered when a lighthouse is to be built upon the sand. This was once thought to be impossible, so that floating lights, or lanterns suspended in the rigging of a vessel, were the only means available in such situations. These were very imperfect, the lights being liable to be hidden by the mist and spray, and the tossing of the vessel, or the ship itself to be blown away from its moorings during violent gales. It is one of the great triumphs of modern engineering, that a permanent residence can now be safely erected on the sand. This is effected by the aid of Mitchell's screw-mooring, which is an instrument consisting of an enormous cast-iron screw *s*, Fig. 1334, of about one turn and a half, having a hollow cylindrical centre: a wrought-iron spindle *s′* passes through the cylindri-

(1) "Account of the Skerryvore Lighthouse, with Notes on the Illumination of Lighthouses." By Alan Stevenson, &c., Engineer to the Northern Lighthouse Board. 4to. Edinburgh, 1848. The Editor has to express his obligations to Mr. Stevenson for the liberal manner in which he has allowed him to make use of this work in the preparation of this article.

cal socket, and is fixed thereto by a forelock passing through both; it is formed with a square head *h*, to receive the key for screwing it into the ground; also with a collar *c* of wrought-iron, fitted so as to turn freely on the upper part of the shaft of the spindle, below the collar. The first experiment made with

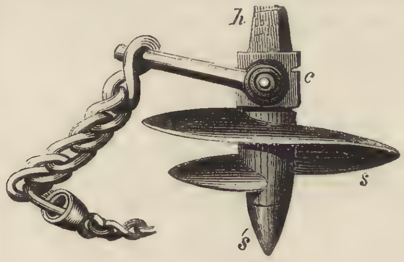


Fig. 1334.

this instrument, with a view to its adaptation to lighthouses, was on the verge of the Maplin Sand, at the mouth of the Thames. Nine of the mooring-screws were inserted into the sands, one serving as a centre to the remainder, which occupied the angles of an octagon 42 feet in diameter. The screws were turned into the sands to the depth of 21½ feet, the upper extremity being left standing about 5 feet above the surface of the sands. A raft of timber was floated over the spot with a capstan in the centre, fitted on the top of an iron shaft, and firmly keyed to it. Thirty men working at the capstan drove the screws firmly into the sand, after which the heavy raft was allowed to remain, and was sunk into the sand by means of about 200 tons of rough stone. The whole mass soon became embedded, and after remaining in that state for about two years, the screw-piles also standing firmly, a lighthouse was erected, and a dioptric fixed light exhibited on this dangerous spot, 16th of February, 1841. This was not, however, the first screw-pile lighthouse actually erected, for during the long preparatory process which was carried on at the Maplin Sands, a structure on the same principle had been begun and completed at Port Fleetwood, on the Wyre, near Lancaster. The preparatory steps were similar to those already described. The foundation of this lighthouse was formed of seven screw-piles, six of them occupying the angles of a hexagon 46 feet in diameter, the seventh being in the centre. From each screw proceeds a pile 15 feet in length, having at the upper end another screw for securing a wooden column. These columns are of Baltic timber, the one in the centre being 56 feet, the others 46 feet in length, firmly secured with iron hoops, and coated with pitch. The platform upon which the house stands is 27 feet in diameter, the house itself being 20 feet diameter, and 9 feet high. From the summit of the house rises a twelve-sided lantern, 10 feet diameter, and 8 feet high. Altogether, the light is elevated about 46 feet above low water level, and ranges over an horizon of 8 miles. The light is of the dioptric kind, bright, steady, and uniform, and when the weather is too foggy to allow it to be seen, a bell is tolled by machinery, to give the needful warning. This useful building was erected in two months, and those the shortest of the year, so that a great part of the work was done by torchlight or moonlight.

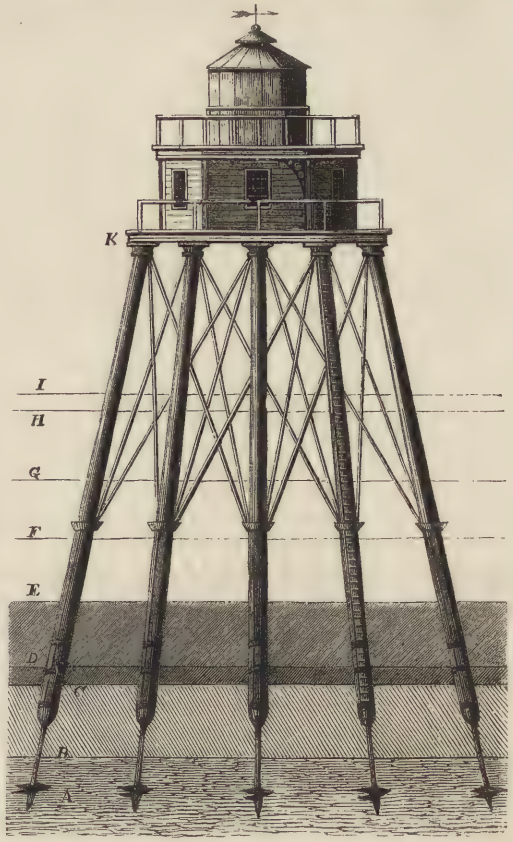


Fig. 1335. SCREW-PILE LIGHTHOUSE ERECTED AT PORT FLEETWOOD, ON THE WYRE, NEAR LANCASTER.

A. Formation of marl into which the screws are driven to the depth of ten feet below low-water mark.

B. Substratum of sand.		
C. Low water, equinoctial springs.		
D. Low water, ordinary tides,	2 feet above C.	
E. ditto neap tides,	9	"
F. Half tide level,	15	"
G. High water neaps,	21	"
H. ditto ordinary tides,	28	"
I. ditto equinoctial springs,	30	"
K. Underside of Platform,	45	"
Centre of the dioptric light in lantern,	60	"

At the time that screw-pile lighthouses were being thus successfully erected, other and most valuable suggestions were being made for the building of bronze and cast-iron lighthouses. The great advantages of iron over stone and other materials, in those portions of the building not actually in contact with sea-water, soon became apparent. Upon a given base, a much larger internal capacity could be obtained; plates could be cast in large surfaces, and with few joints; and a system of bonding adopted, which should ensure the perfect combination of every part. The comparatively small bulk and weight also of the component parts, gave great facilities for the transport and rapid erection of such structures.

The first cast-iron lighthouse was designed by Mr. Gordon in 1840, and was cast, and put together

within three months from the date of the contract. It was then taken to pieces, and shipped for Jamaica, on which island it now lights up a dangerous point, called Morant Point. The commissioners of the House of Assembly had applied to Mr. Gordon, to supply a suitable lighthouse at the smallest possible cost; and in furnishing them with this structure of cast-iron, he fulfilled their wishes admirably, the expense not exceeding one-third of the cost of a similar building in stone. This elegant lighthouse, the outline of which resembled that of the Celtic Towers of Ireland, was visited by the writer while it stood complete in the contractor's premises. The diameter of the tower is 18 feet 6 inches at the base, diminishing to 11 feet under the cap. The tower is formed of nine tiers of iron plates, each tier being 10 feet high, and about $\frac{3}{4}$ inch thick. At the base of the structure 11 plates are required to form the circumference, at the top 9 plates; they are cast with a flange around their inner edges, and when put together these flanges form the joints, which are fastened together with nut and screw bolts, and caulked with iron cement. The interior of the tower to the height of 27 feet, was to be filled up with masonry and concrete of the weight of 300 tons; the remainder is divided into store rooms and berths for the attendants. The tower is finished by an iron railing, within which rises the light-room, also of cast-iron, with windows of plate glass. A copper roof, and a short lightning rod, complete the whole. The Admiralty notice announced the exhibition of this light on Morant Point, November 1, 1842, and stated that the elevation of the light is 96 feet above the level of the sea, and that in clear weather it is visible at a distance of 21 miles. The light is of the revolving kind, consisting of 15 Argand lamps and reflectors, five in each side of an equilateral triangle, and so placed as to produce a continuous light, but with periodical flashes. The tower is painted white, and the lower portion is coated with coal-tar to preserve it from rust. It rests on a granite base, and is also cased with granite near the foundation, the more certainly to prevent the action of the sea-water on the metal.

It will be seen from the foregoing details that while the engineer had attained some of his greatest triumphs in the construction of lighthouses, the optician had not once directed his attention to the invention of a brilliant light, worthy to be placed upon the structure which proudly rose high above the fierce waves, with the strength and solidity of a rock. During a period of forty years after the completion of the Eddystone tower by Smeaton, the lantern was illuminated by tallow candles stuck in hoops, just as a show-booth is lighted at a country fair, and so lately as the year 1811 it was lighted with 24 wax candles. In 1812, the Lizard light was maintained with coal fires; and in 1816, when the Isle of May light, in the Frith of Forth, was taken possession of by the Commissioners of the Northern Lighthouses, a coal fire was exhibited in a chauffer,—a description of light which had been exhibited for 181 years. In 1801, the light at Harwich, in addition to the coal fire, had a *flat* plate of rough brass on the landward side, to serve as a reflector. Such methods of lighting were, of course, very defective in power, and did not enable the mariner to distinguish one light from another—a point which is often of as much importance as the brilliancy of the light itself.

Previous to the invention of the Argand lamp (about 1784), the production of a strong and brilliant light from a single source was scarcely possible. And even such a lamp, by its unassisted powers, would not be of very great value in giving early notice to the mariner of his approach to the coast, which ought to be the primary object of a lighthouse. As the rays from a luminous body proceed in all directions in straight lines, it is obvious that in the case of a single lamp, the mariner would derive benefit only from that small portion of light which proceeded from the centre of the flame to his eye. The other rays would proceed to other parts of the horizon, or escape upwards to the sky, or downwards to the earth, and thus be of no value to him. By increasing the number of burners, a small portion of light from each burner would slightly increase the effective action, but by far the greatest portion of the light produced would escape uselessly above and below the horizon, and also at the back of each flame.

Now, these defects may be remedied, and the efficiency of the light greatly increased, by placing behind each lamp a reflector, of such a form as to collect the rays that would otherwise be lost, and throw them forward to the horizon. The adoption of such a method has led to what is called the CATOPTRIC [1] *system* of lights.

Mr. Stevenson states that the earliest notice which he has been able to find of the application of paraboloidal mirrors to lighthouses, is in a work on "Practical Seamanship," (4to., Liverpool, 1791,) by Mr. William Hutchinson, who notices the erection of the four lights at Bidstone and Hoylake for the entrance of the Mersey, in 1763, and describes large paraboloidal moulds of wood lined with mirror-glass, and smaller ones of polished tin plate, as in use in those lighthouses. In France, M. Teulère, a member of the Royal Corps of Engineers of Bridges and Roads, is regarded as the inventor of the catoptric system of lights. In a memoir dated 26th June, 1783, he is said to have proposed for the Corduan lighthouse a combination of paraboloidal reflectors with Argand lamps, ranged on a revolving frame; a plan which was actually carried into execution under the directions of the Chevalier Borda. The plan was so successful that it was soon adopted in England by the Trinity House of London; and in Scotland the first work of the Northern Lights Board, in 1787, was to light a lantern on the old castle at Kinnaird Head, in Aberdeenshire by means of parabolic reflectors and lamps. These reflectors were formed of facets of mirror-glass placed in hollow paraboloidal moulds of plaster.

Referring to what has been already said respecting

(1) From κάτοπτρον, *a mirror*; a compound of κατὰ, *opposite to*, and ὄπτομαι, *I see*.

the reflection of rays of heat, [see HEAT, Fig. 1137,] it will be desirable now to explain a little more fully the laws of reflection by mirrors.

When luminous rays fall upon any surface which does not absorb them, they reflect or rebound from such surface, not precisely after the manner of solid projectiles, but by a much simpler law, which is applicable to projectiles only on the supposition that they move through a vacuum, are endowed with perfect elasticity, and have no weight. This law of reflection applies to heat and sound, as well as light; in short, to those radiations or effects which are propagated in straight lines only. Each line or *ray* proceeds in a straight line until it meets with a reflecting surface, from which it rebounds in another straight line, the direction of which is determined by the invariable law, which, for plane surfaces, may be stated in two parts:—

I. That the imaginary plane which contains the ray both before and after reflection (or, as they are called, the *incident* and *reflected* rays) is perpendicular to the reflecting plane. [See HEAT, Fig. 1136.]

II. That the incident and the reflected ray make equal angles with the reflecting plane, or with a perpendicular thereto. [See Fig. 1136.]

When the reflecting surface is curved, we have only to remember that each mathematical point of such surface acts precisely as a tangent plane would do; that is, as a plane touching the curved surface at that point. Hence, certain regularly-curved reflecting surfaces possess some valuable and remarkable properties. For example: all the radii of a *spherical* surface are perpendicular to it, and all meet at one point. If, therefore, we place a lamp in the centre of concavity of a concave spherical mirror properly polished, all the rays of light will be reflected back to the same point whence they came. Again, an *ellipse* bears certain relations to two fixed points within it, called the *foci*.[1] One of these relations is, that a tangent to the curve at any point makes equal angles with the two lines drawn from that point to the foci; so that, if a tennis-court were built in the form of an ellipse, a ball thrown from one of the foci, in whatever direction, would, after its rebound, proceed directly towards the other focus. Now, an *oblong spheroid*[2] possesses this property not only in a horizontal plane, but in every plane that contains its two foci. Consequently, if we had a hollow oblong spheroid, with its inner surface polished, all rays whatever radiating from one of its foci would, after one rebound, proceed to the other focus, where they would all meet.

Now if, instead of the whole spheroid, we had only a portion of one,—one end, for example, or a ring from the middle, or only a portion of such a ring, however small,—it would still be true of all rays intercepted by this mirror, and coming from one of its foci, that they would all be reflected to the other focus. But as it is not easy to produce such a spheroidal surface, the remarkable effects produced by the meeting of all the rays in one point (as noticed under HEAT, p. 12) are commonly shown in an inferior manner by means of two reflections from two mirrors which are made as nearly like *paraboloids*[3] as possible. Now a paraboloid may be regarded as one end of an oblong spheroid, of which the further focus is at an infinite distance. When rays, therefore, radiate from the nearer focus, they are all reflected towards a point infinitely distant; that is to say, they are all rendered parallel; and conversely, any number of parallel rays coming to such a mirror are all reflected so as to meet in its focus.

In reasoning on this subject, we suppose the source of light to be a mathematical point in the focus of the mirror; in which case, the rays proceeding in parallel directions, and not spreading as they proceeded, would suffer no decrease of power except that which arose from the very minute resistance of the air. But as in practice the rays proceed from the innumerable points of a large flame, only one of which points is in the focus of the mirror, the rays evidently cannot all be reflected parallel with its axis. We may here remark, that the whole effect, whether light or heat, which radiates from any *one* point, is called a *pencil*, and is of course divisible into an infinite number of lines or *rays*, all of which are rendered by the reflection perfectly parallel, and they then constitute a *simple parallel beam*. But as the lamp-flame, however small, emits an infinite number of pencils, one from each point of its surface, these become after reflection an infinite number of simple beams; and although each of these alone does not spread in its progress, but fills only a cylindrical space of the exact diameter of the mirror, yet, as all their directions slightly differ, they altogether form a *compound beam*, which does spread wider and wider as it proceeds.

Now suppose it were required to exhibit to the mariner in every part of the horizon pencils of light at certain intervals of time, separated by periods of darkness; the best method would evidently be to cause lamps, placed in the foci of paraboloidal mirrors, to revolve round a vertical axis, with a velocity suited to produce the required number of flashes in a given time. Such an arrangement is shown in the following figures. The reflectors are made of sheet copper, plated in the proportion of six ounces of silver to sixteen ounces of copper. They are moulded to the paraboloidal form by a delicate and laborious process of beating with mallets and hammers of various forms and materials, and are frequently tested during the operation by the application of a carefully-formed mould. After having been brought to the proper curve, they are stiffened round the edge by means of

(1) In the carpenter's method of drawing an ellipse, by means of two nails and a piece of string, the nails occupy the *focal* points.

(2) An oblong spheroid is produced when an ellipse is made to revolve on its longer axis. It resembles an egg, of which both the ends are alike. Every plane that touches it makes equal angles with the two lines from the point of contact to the foci,—whence its peculiar reflecting property.

(3) A paraboloid is produced when a parabola is made to revolve on its axis. As a parabola may be regarded as a portion cut off one end of an ellipse of infinite length, a paraboloid is one end of an infinitely long oblong spheroid. Every plane touching it makes equal angles with two lines drawn from the point of contact, one to the focus and the other parallel with the axis.

a strong bizzle and a strap of brass which is attached to it for the purpose of preventing any accidental alteration of the figure of the reflector. Polishing-powders are then applied, and the speculum receives its last finish. Some idea may be formed of the amount of labour bestowed upon these reflectors from the prices paid to the manufacturer; namely, for the large reflectors of 24 inches aperture, 43*l.* each; for the small ones of 21 inches, 31*l.* 12*s.* The lamp with the sliding carriage required for each costs 6*l.*

The flame generally used in reflectors is from an Argand fountain lamp, the wick of which is one inch in diameter. In some cases the burners are tipped with silver, to prevent the corrosion of the more common metal from the great heat evolved. The burners are also fitted with a sliding apparatus, which allows them to be removed from the interior of the mirror for cleaning, and returned exactly to the same place, where they are locked by a key. By this contrivance the burner is always kept in the same focus, and the lamp can be moved in and out without disturbing the reflector. In Fig. 1336, *a a* represents a section of the reflector, *b* the burner, with the glass chimney *b′*, and *c* a cylindrical fountain containing twenty-four ounces of oil: *l* is an oil-cup for receiving any oil that may drop from the lamp. The oil-pipe, the fountain *c*, and the burner *b* are connected with the rectangular frame *d*, Fig. 1337, movable in a vertical direction upon the guide-rods *e* and *f*, by which it can be let down and the burner lowered out of the reflector, by turning the handle *g*, which forces a thread on the outside of the guide into a groove in the frame, or withdrawing it, which allows it to slide down or locks it at pleasure. In Fig. 1337, the fountain *c* is represented moved partly down: *e e* are elongated socket-guides, through which the guide-rods slide; and *f* is the guide-rod, connected with the perforated sockets on which the checking-handle *g* slides. The oil-cup *l*, when covered with a lid and wick-holder, as shown in Fig. 1338, also serves as a *frost-lamp* in winter, when the oil is liable to congeal. It is attached to the lower part of the oil-tube by the arm *h*, and is lighted about an hour before sunset, so as to prepare the large lamp for lighting at the proper time. The communication between the burner and the fountain is easily opened or shut by simply giving the fountain a turn of one quadrant round its own vertical axis, by means of the round knob at its top, thereby moving a slide-valve which shuts off the communication between the fountain-tube and the lamp-tube. [See Lamp.] By this means, the oil is cut off about fifteen minutes before extinguishing the lights, so that when that is done, the burner is quite free from oil. The wick is raised and depressed by a rack and pinion, as noticed under Lamp. An elliptical aperture, 2 inches by 3, is cut in the upper and lower part of the reflector; the lower serving for the free ingress and egress of the burner, and the upper, to which the copper tube *h* is attached, serving for ventilation. At *i* is a portion of the main bar of the chandelier or frame on which the reflectors are ranged, each being made to rest on knobs of brass, one of which, shown at *k k*, Fig. 1339, is soldered to the brass band *l*, that clasps the exterior of the reflector.

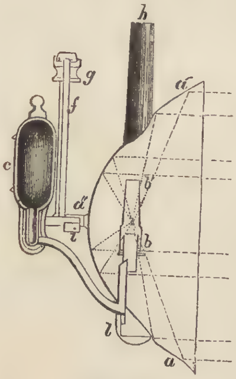


Fig. 1336.

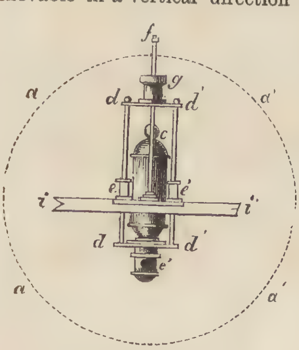


Fig. 1337.

Fig. 1338.

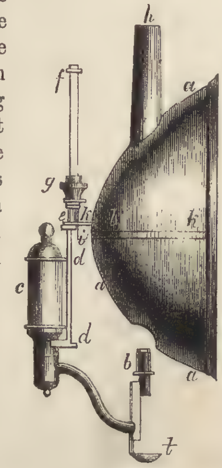


Fig. 1339.

The oil generally used in the lighthouses of the United Kingdom is the sperm oil of commerce. In France, the colza oil, which is expressed from the seed of a species of wild cabbage (*Brassica oleracea colza*), and the olive oil, are chiefly used. Colza oil has recently been adopted in many of the British lights, and has led to an important saving, as its combustion produces an equal quantity of light at little more than one-half of the expense of sperm oil. It also possesses over sperm oil other advantages, which were stated by Stevenson in his Report on this subject to a select Committee of the House of Commons on Lighthouses, 10th March, 1847. It remains fluid at temperatures at which sperm oil thickens: its illuminating power is somewhat superior to that of sperm oil, in the ratio of 1·056 to 1. It burns both in the Fresnel lamp and the single Argand burner, with a thick wick, during 17 hours, without requiring any coaling of the wick or any adjustment of the damper, and the flame appears to be more steady than that produced by sperm oil. This greater steadiness of the colza-oil flame involves less breakage of the glass chimneys than with sperm oil. The consumption of oil in the Fresnel lamp is stated at 121 for colza, and 114 for sperm: in the Argand lamp, 910 for colza, and 902 for sperm. Assuming the means of these numbers, 515 for colza, and 508 sperm, as representing the relative expenditure of these oils, and if the price of colza be 3*s.* 9*d.* and sperm 6*s.* 9*d.* per gallon, the saving is in the ratio of 1 to 1·755, which at the present rate of supply for the Northern

Lights would give a saving of about 3,266*l.* per annum. It should be stated, that in the use of colza oil in lamps which had previously burned sperm, the burners require to be re-constructed so as to receive thick wicks of brown cotton.

The number of lights on a much-frequented coast being considerable, it is of the utmost importance to arrange them so as to enable the mariner easily to distinguish them from each other. Catoptric lights admit of nine separate distinctions: 1, *fixed*, 2, *revolving white*, 3, *revolving red and white*, 4, *revolving red with two whites*, 5, *revolving white with two reds*, 6, *flashing*, 7, *intermittent*, 8, *double fixed lights*, 9, *double revolving white lights*. Mr. Stevenson thus defines their distinctive features:—"The first exhibits a steady and uniform appearance, which is not subject to any change; and the reflectors used for it are of smaller dimensions than those employed in revolving lights. This is necessary in order to permit them to be ranged round the circular frame, with their axes inclined at such an angle as shall enable them to illuminate every point of the horizon. The *revolving* light is produced by the revolution of a frame with three or four sides, having reflectors of a larger size grouped on each side with their axes parallel; and as the revolution exhibits once in two minutes, or once in a minute, as may be required, a light gradually increasing to *full strength*, and in the same gradual manner decreasing to total darkness, its appearance is extremely well marked. The succession of *red and white* lights is caused by the revolution of a frame whose different sides present red and white lights; and these afford three separate distinctions, namely, alternate red and white; the succession of two white lights after one red; and the succession of two red lights after one white light. The *flashing* light is produced in the same manner as the *revolving* light; but owing to a different construction of the frame, the reflectors on each of eight sides are arranged with their rims or faces in one vertical plane, and their axes in a line inclined to the perpendicular; a disposition of the mirrors which, together with the greater quickness of the revolution, which shows a flash once in five seconds of time, produces a very striking effect, totally different from that of a revolving light, and presenting the appearance of the flash alternately rising and sinking. The brightest and darkest periods being but momentary, this light is further characterised by a rapid succession of bright flashes, from which it gets its name. The *intermittent* light is distinguished by bursting suddenly into view and continuing steady for a short time, after which it is suddenly eclipsed for half a minute. Its striking appearance is produced by the perpendicular motion of circular shades in front of the reflectors by which the light is alternately hid and displayed. This distinction, as well as that called the *flashing light*, is peculiar to the Scotch coast. The double lights (which are seldom used except where there is a necessity for a *leading* line, as a guide for taking some channel, or avoiding some danger) are generally exhibited from two towers, one of which is higher than the other. At the Calf of Man a striking variety has been introduced into the character of leading lights, by substituting for two *fixed* lights, two lights which revolve in the same periods, and exhibit their flashes at the same instant; and these lights are, of course, susceptible of the other variety enumerated above, that of two revolving red and white lights, or flashing lights, coming into view at equal intervals of time. The utility of all these distinctions is to be valued with reference to their property of at once striking the eye of an observer, and being instantaneously obvious to strangers. The introduction of colour, as a source of distinction, is necessary in order to obtain a sufficient number of distinctions; but it is in itself an evil of no small magnitude; as the effect is produced by interposing coloured media between the burner and the observer's eye, and much light is thus lost by the absorption of those rays which are held back in order to cause the appearance which is desired. Trial has been made of various colours; but red, blue, and green alone have been found useful, and the two latter only at distances so short as to render them altogether unfit for sea-lights. Owing to the depth of tint which is required to produce a marked effect, the red shades generally used absorb from $\frac{4}{7}$ths to $\frac{5}{6}$ths of the whole light,—an enormous loss, and sufficient to discourage the adoption of that mode of distinction in every situation where it can possibly be

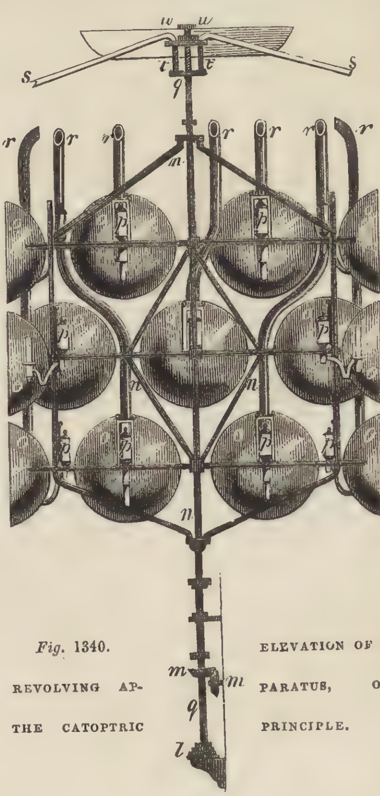


Fig. 1340. ELEVATION OF A REVOLVING APPARATUS, ON THE CATOPTRIC PRINCIPLE.

avoided. The red glass used in France absorbs only $\frac{4}{7}$ths of the light; but its colour produces, as might be expected, a much less marked distinction to the

seaman's eye. In the lighthouses of Scotland, a simple and convenient arrangement exists for colouring the lights, which consists in using chimneys of red glass, instead of placing large discs in front of the reflectors."

The arrangement of a revolving apparatus on the catoptric principle is shown in Figs. 1340, 1341. *n n* represents the reflector frame, or chandelier; *o o* the reflectors with their oil-fountains *p p:* the whole is attached to the revolving axis or shaft *q*, the pivot of

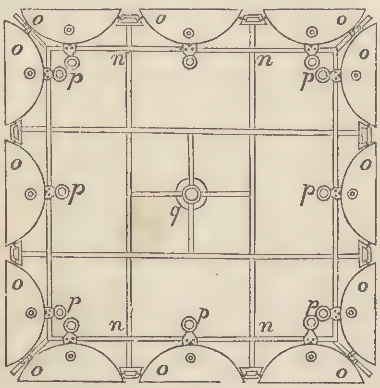


Fig. 1341.

which turns in a cup supported by a cast-iron bracket *l:* the shaft is also supported by cross bars at *s s; m m* are bevelled wheels for conveying motion to the shaft by means of common clockwork machinery moved by a descending weight. The copper ventilating tubes, *r r*, convey away the heated products of combustion; and *u u* is a copper pan for receiving any moisture which may happen to enter at the central ventilator in the roof of the light-room.

Fig. 1342 is a plan of one tier of reflectors arranged for a fixed catoptric light. In order to distribute the light as equably as possible, the other tiers

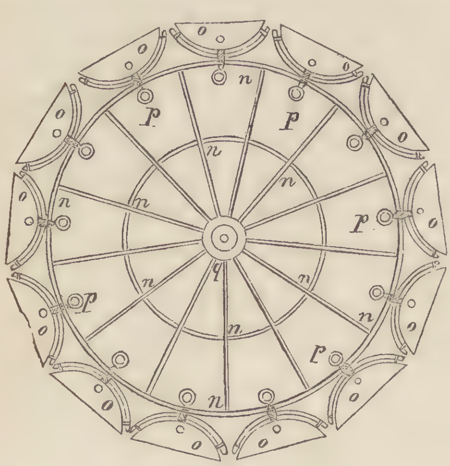


Fig. 1342.

are so arranged that their axes divide into equal angles the arcs intercepted between the axes of the adjoining reflectors on the first tier. In this figure *n n* represents the chandelier, *q* the fixed shaft in the centre, supporting the whole, *o o* the reflectors, and *p p* the lamp-fountains.

"In lighthouses of moderate height the proper position for the reflector itself is perfect horizontality of its axis, which may be ascertained with sufficient accuracy by trying, with a plummet, whether the lips of the instrument, which we may conclude to be at right angles to the plane of its axis, be truly vertical. In light-rooms very much elevated above the sea, however, the dip of the horizon becomes notable; and a slight inclination forwards should be given to the face of the reflectors, so that their axes produced may be tangents to the earth at the visible horizon of the light-room; an arrangement which, in practice, may be easily made by reflecting the sea horizon, in a small mirror placed at the focus, and inclined at 45° to the axis of the paraboloid, so that the image of the sea-line may reach the eye in the line of the parameter. The dip of the reflector, however, must not be permitted to interfere with the perfect horizontality of the top of the burner, which is indispensable to its proper burning."

Various other forms and arrangements of parabolic mirrors have been contrived for lighthouses and harbour lights, but our limited space will not allow us to describe them.

We come next to notice what is called the DIOPTRIC *system* of lights.[1] In the *catoptric* system, as already explained, the light is reflected from a surface formed in such a way as to cause all the rays to proceed in one and the same required direction. In the *dioptric* system the rays are made to pass through lenses, by which they are *bent* or *refracted* from their natural course into that which is desired. The same object is attained by either system, only in the one case the light is *reflected*, and in the other it is *refracted*.

One of the earliest notices of the application of lenses to lighthouses, is by Smeaton in his narrative of the Eddystone Lighthouse, where it is mentioned that a London optician proposed to grind the glass of the lantern to a radius of $7\frac{1}{2}$ feet. But before this lenses had actually been tried in several lighthouses in the north of England, and in particular at the South Foreland in 1752; but their imperfect figure, and the quantity of light absorbed by the glass, rendered their effects so much inferior to that of the paraboloidal reflectors as to lead to their being abandoned for a time. Indeed the obstacles in the way of forming accurate lenses of large size and in one piece may be fairly pronounced insurmountable; for in the *first* place, pure flint glass free from *striæ, knots, threads* and *tears*, cannot be produced in sufficient abundance for a large solid lens [see GLASS, Section V.]: *secondly*, it cannot be cast into a lenticular form without flaws and impurities which grinding and polishing will not remove; *thirdly*, the great increase of thickness in the centre consequent on an increase in diameter of the lens, opposes the transmission of the luminous rays, and by increasing the aberration

(1) Probably from δίοπτρον, an optical instrument with holes for looking through: from διά, *through;* ὄπτομαι, *I see.*

dissipates the rays at the focal point. In order to get rid of these objections, Buffon proposed that a solid lens of large size having been formed, the parts not necessary to the general optical effects should be cut away. For example, in the solid lens of the section A *mp* B E D A, Fig. 1343, it was proposed to cut out all the glass left white in the figure, namely, the portions between *mp* and *no*, and between *no* and the left-hand surface of D E. A lens thus constructed would be incomparably superior to the solid one, but it would be very difficult to polish the surfaces A *m*, B *p*, C *n*, F *o*, and the left-hand surface of D E; and after all some of the greatest blemishes in the glass might be left in the lens thus formed. It was therefore a capital suggestion to build up

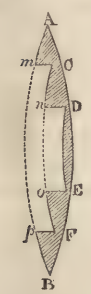


Fig. 1343.

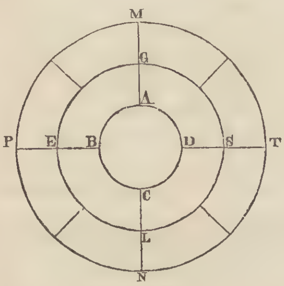


Fig. 1344.

lenses of any size of separate zones or rings, each of which might be composed of separate segments, as shown in the front view of the lens, Fig. 1344.[1] Such a lens is composed of one central lens A B C D, corresponding with its section D E, Fig. 1343; of a middle ring G E L S, corresponding to C D E F, Fig. 1343, and consisting of four segments; and another ring, N P M T, corresponding to A C F B, and consisting of eight segments. Such lenses, named by Sir David Brewster *polyzonal*, can be formed of large size, and by making the foci of each zone coincide, the spherical aberration can be corrected or nearly so. This invention was followed up by Fresnel, who, in conjunction with Arago and Mathieu, placed a powerful lamp in the focus of the lens, and applied it to the practical purposes of a lighthouse. Fresnel also determined the radius and centre of the curvature of the generating arcs of each zone, centres which continually recede from the vertex of the lens in proportion as the zones to which they refer are removed from its centre; and the surfaces of the zones, consequently, are not, as in Buffon's lens, parts of concentric spheres. It deserves notice that the first lenses constructed for Fresnel by M. Soleil, had their zones polygonal, so that the surfaces were not annular, a form which Fresnel considered less accommodated to the ordinary resources of the optician. He also, with his habitual penetration, preferred the plano-convex to the double-convex form, as more easily executed. After mature consideration, he finally adopted crown glass, which, notwithstanding its greenish colour, he preferred to flint glass, as being more free from striæ. All his calculations were made in reference to an index of refraction of 1·51, which he verified by repeated experiments. The instruments have received the name of *annular* lenses, from the figure of the surface of the zones."

The Dutch first followed the French in introducing the system of Fresnel into their lighthouses. In 1824 the Commissioners of the Northern Lighthouses sent their engineer, Mr. Robert Stevenson, to France, and to report upon the lights of that country, which he did within the same year, and also procured lenses from France for the purpose of instituting experiments. In a report dated 30th Dec. 1825, he recommended the adoption of lenses. It was not, however, until 1834 that the commissioners took decisive steps for deciding the comparative merits of the catoptric and dioptric systems. In that year Mr. Alan Stevenson was commissioned to visit France, and make himself perfectly acquainted with the dioptric system, and the result of his report was such, that on his return the Commissioners authorized him to remove the reflecting apparatus of the revolving light at Inchkeith, and to substitute dioptric instruments in its place, a change which was completed and the light exhibited on the evening of the 1st October, 1835. The light was so highly satisfactory that a similar change was made at the fixed light of the Isle of May. The Trinity House next adopted the system for England, and employed Mr. Alan Stevenson to superintend the construction of a revolving dioptric light of the first order, which was afterwards erected at the Start Point in Devonshire. After this time the system became common.

Referring to our article LIGHT for a notice of the laws of refraction and the action of lenses upon luminous rays, it will be sufficient to remind the reader of the following properties of a plano-convex lens such as L *l*, Fig. 1345. *f* A *r* is the optical axis of the lens, or the line in which a ray of light passes through the lens without any change of direction, in consequence of its being normal to both surfaces. *f* is the principal focus or the point where the rays *r r r*, which fall parallel to the optic axis on the outer face of the lens, meet after refraction at the two faces. Or if we suppose *f* to be a point of light, the rays proceeding from it in their naturally divergent course fall on the inner surface L A *l* of the lens, and are so changed by refraction there and at the outer face, that they finally emerge parallel to the optic axis in the direction L *r*, *l r*. A spherical lens collects truly into the focus only those rays which are incident near the axis, and hence it is of importance to employ as a lens only a small segment of a sphere. This circumstance, among others, led to the suggestion of building up lenses in separate pieces, and Fresnel, as already noticed, showed how the subdivision was to be

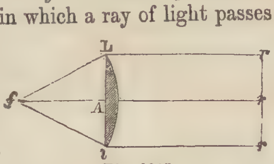


Fig. 1345.

(1) This suggestion was *first* made by Condorcet in his "Eloge de Buffon," published in 1773; *secondly*, by Sir David Brewster in 1811; and *thirdly*, by Fresnel in 1822. They all appear to have been perfectly original and independent suggestions.

made. In his large lens employed in lights of the first order, the focal distance of which is 920 millimètres, or 36·22 inches, the central disc is about 11 inches in diameter, and the annular rings which surround it gradually decrease in breadth as they recede from the axis, from 2 ¾ to 1 ¼ inches. The breadth of any zone or ring may, however, be left to choice, but no part of the lens should be much thicker than the rest, otherwise there would be inconvenient projections on its surface, and the loss of light by absorption would be unequal. In the first lenses the zones were united by means of small dowels or joggles of copper passing from the one zone into the other, but the French artists have now attained such exactness in their work as to dispense with such fixtures, and the various parts of the compound lens, weighing upwards of 100 lbs. and presenting about 1,300 square inches of surface,

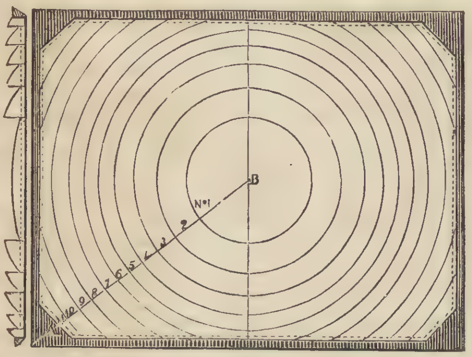


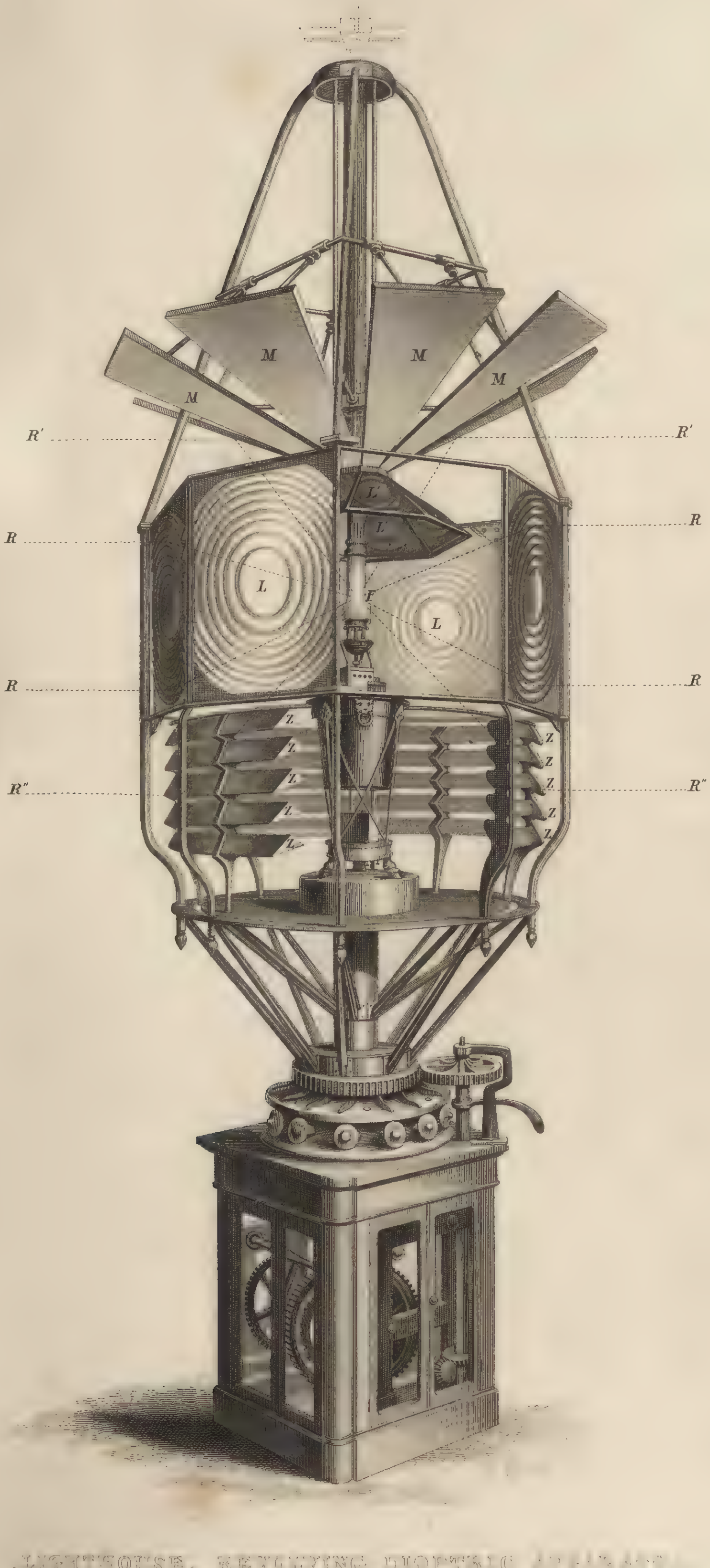
Fig. 1346. ANNULAR LENS OF THE FIRST ORDER.

are now bound together solely by a metallic frame, Fig. 1346, and the close union between the concentric faces of the rings, although the surfaces in contact with each other are only ¼ inch in depth.

As to the illuminating power of the lenses, Mr. Stevenson says, "We shall not greatly err if we consider the quotient of the surface of the lens divided by the surface of the flame, as the increased power of illumination by the use of the lens. The illuminating effect of the great lens, as measured at moderate distances, has generally been taken at 3,000 Argand flames, the value of the great flame in its focus being about 16, thus giving its increasing power as nearly equal to 180. The more perfect lenses have produced a considerably greater effect."

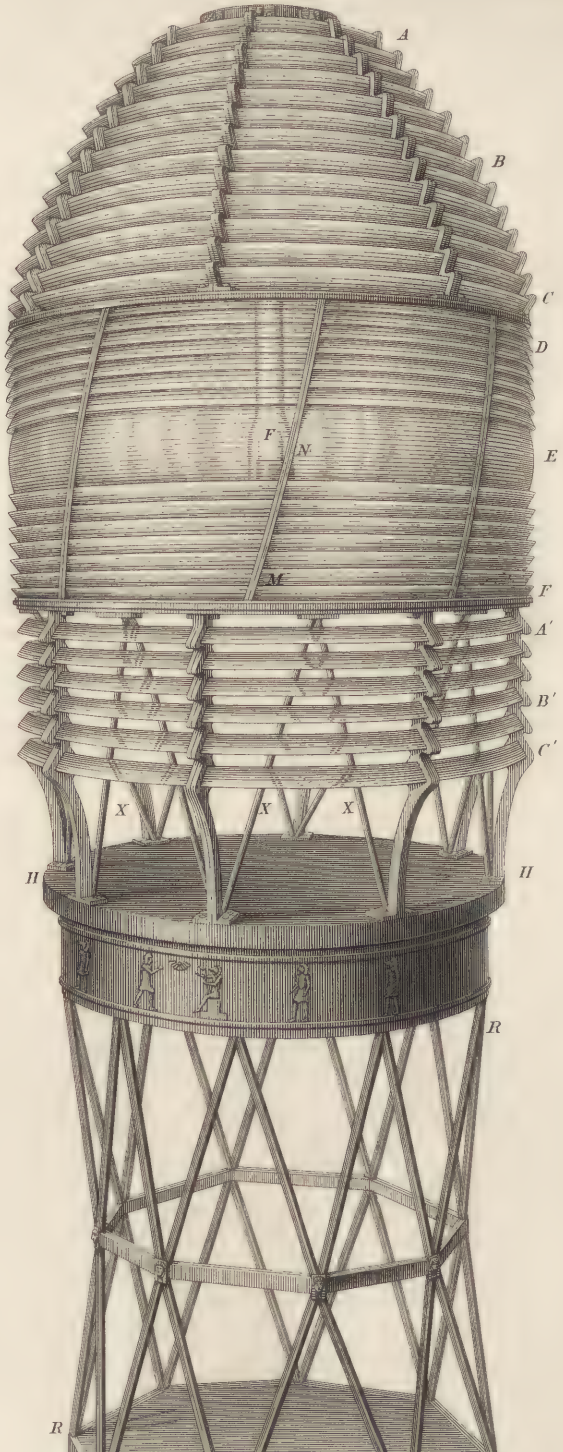
In the application of lenses to lighthouses, they are arranged round a central lamp placed on the level of their focal plane, as shown in Plate I, thus forming by their union a right octagonal hollow prism circulating round the fixed central flame, and showing to a distant observer successive flashes or blazes of light whenever one of its faces crosses a line joining his eye and the lamp. Thus the action is somewhat similar to that of the mirrors; but the blaze produced by the lens is of greater intensity and shorter duration, the latter quality being proportional to the divergence of the resultant beam. "Each lens subtends a central horizontal pyramid of light of about 46° of inclination, beyond which limits the lenticular action could not be advantageously pushed, owing to the extreme obliquity of the incidence of light; but Fresnel at once conceived the idea of pressing into the service of the mariner, by means of two very simple expedients, the light which would otherwise have uselessly escaped above and below the lenses. For intercepting the upper portion of the light, he employed eight smaller lenses of 500 mm. focal distance (19·68 inches) inclined inwards towards the lamp, which is also their common focus, and thus forming by their union a frustum of a hollow octagonal pyramid of 50° of inclination. The light falling on those lenses is formed into eight beams rising upwards at an angle of 50° inclination. Above them are arranged eight plane mirrors, so inclined (see Plate I.) as to project the beams transmitted by the small lenses into the horizontal direction, and thus finally to increase the effect of the light. In placing those upper lenses, it is generally thought advisable to give their axes a horizontal direction of 7° or 8° from that of the great lenses, and in the direction contrary to that of the revolution of the frame which carries the lenticular apparatus. By this arrangement, the flashes of the smaller lenses precede those of the large ones, and thus tend to correct the chief practical defect of revolving lenticular lights, by prolonging the bright periods. . . . Owing to certain arrangements of the apparatus, which are necessary for the efficiency of the lamp, but a small portion of those rays which escape from below the lenses can be rendered available for the purposes of a lighthouse; and any attempt to subject them to lenticular action, so as to add them to the periodic flashes, would have led to a most inconvenient complication of the apparatus. Fresnel adopted the more natural and simple course of transmitting them to the horizon in the form of flat rings of light, or rather of divergent pencils, directed to various points of the horizon. This he effected by means of small curved mirrors, disposed in tiers one above another, like the leaves of a Venetian blind, an arrangement which he also adopted for intercepting the light which escapes above as well as below the dioptric belt in fixed lights. The mirrors are plates of glass silvered on the back, and set in flat cases of sheet brass. They are suspended on a circular frame by means of screws, which being attached to the backs of the brass cases, afford the means of adjusting them to their true inclination, so that they may reflect objects on the horizon of the lighthouse to an observer's eye placed in the common focus of the system."

Plate I. represents a *revolving* dioptric apparatus, in which F is the focal point in which the flame is placed; L L large annular lenses forming by their union an octagonal prism, with the lamp in its axis, and projecting in horizontal beams the light which they receive from the focus. L′ L′ are the upper lenses, forming by their union a frustum of an octagonal pyramid of 50° of inclination, and having their foci corresponding in the point F. They parallelise the rays of light which pass over the lenses. M M



LIGHTHOUSE. REVOLVING DIOPTRIC APPARATUS.

First order.


A
B
C
D
F
N
E
M
F
A′
B′
C′
X
X
X
H
H
R
R

are the plane mirrors placed above the pyramidal lenses L′ L′, and so inclined as to project the beams reflected from them in planes parallel to the horizon. Z Z are the lower zones substituted by Mr. Stevenson for the curved mirrors, as will be further noticed presently. The lower part shows the movable framework, which carries the lenses, and mirrors, and the rollers on which it circulates, with the clock-work for giving motion to the whole.

Plate II. represents a *fixed* catadioptric apparatus. In this as well as in the former case the lamp is, of course, in the centre, but in the first case the lenses form an *octagonal hollow prism* circulating round the flame; and in the second case, a *polygonal hoop* consisting of a series of refractors infinitely smaller in their length, and having their axes in planes parallel to the horizon. Such a continuation of vertical sections, by refracting the rays proceeding from the focus only in the vertical direction, must distribute a zone of light equally brilliant in every point of the horizon. This effect will be easily understood by considering the middle vertical section of one of the great annular lenses already described, abstractedly from its relation to the rest of the instrument. It will readily be perceived that this section possesses the property of simply refracting the rays in one plane coincident with the line of the section, and in a direction parallel to the horizon, and cannot collect the rays from either side of the vertical line; and if this section by its revolution about a vertical axis becomes the generating line of the enveloping hoop above noticed, such a hoop will of course possess the property of refracting an equally diffused zone of light round the horizon. The difficulty, however, of forming this apparatus appeared so great, that Fresnel determined to substitute for it a vertical polygon composed of what have been improperly called *cylindric lenses*, but which in reality are mixtilinear prisms placed horizontally, and distributing the light which they receive from the focus almost equally over the horizontal sector which they subtend. This polygon has a sufficient number of sides to enable it to give, at the angle formed by the junction of two of them, a light not very much inferior to what is produced in the centre of one of the sides; and the upper and lower courses of curved mirrors are always so placed as partly to make up for the deficiency of the light at the angles. The effect sought for in a fixed light is thus obtained in a much more perfect manner than by any conceivable combination of paraboloidal mirrors. . . . The disadvantage of the polygon lies in the excess of the radius of the circumscribing circle over that of the inscribed circle, which occasions an unequal distribution of light between its angles and the centre of each of its sides; and this fault can only be fully remedied by constructing a cylindric belt, whose generating line is the middle mixtilinear section of an *annular* lens revolving about a vertical axis passing through its principal focus. This is, in fact, the only form which can possibly produce an equal diffusion of the incident light over every part of the horizon. Such an apparatus as is here indicated, was constructed under the directions of Mr. Alan Stevenson for the Isle of May light. It was of a truly cylindric form, with its central belt in one piece, and the joints of each panel inclined to the horizon at such an angle as to render the light perfectly equal in every azimuth. See Plate II.

Another improvement which we owe to Mr. Stevenson, was the substitution of totally reflecting prisms for the mirrors before employed in conjunction with the lenses. Mirrors have the objection of occasioning loss of light by reflection, and of being composed of perishable materials as regards their polish. Such a catadioptric apparatus was constructed by M. Soleil, at Paris, and tested by M. Léonor Fresnel, at the Royal Observatory of that city, when the illuminating effect of the cupola of zones was found to be to that of the seven upper tiers of mirrors of the first order, as 140 to 87. This apparatus, which was fitted up in the Skerryvore Lighthouse, and is represented in Plate II., consists of a central dioptric belt of refractors, D E F, forming a hollow cylinder of 6 feet in diameter and 30 inches high; below it are six triangular rings of glass, A′ B′ C′, or catadioptric zones, ranged in a cylindrical form, and above, a crown of 13 rings of glass, A B C, the whole forming by their union a hollow cage composed of polished glass 10 feet high and 6 feet in diameter. In the lower catadioptric zones one division is omitted, to allow free access to the lamp. F is the focus with the lamp-flame. X X X are diagonal supports for the upper catadioptric zones; H H a service-table, on which the lamp rests, and on which the keeper stands to trim the burner: this table is supported by a pillar resting on the light-room floor.

The single central lamp required for dioptric apparatus must be so constructed as to afford a large volume of flame, for which purpose the burner is made to consist of four concentric wicks, as shown in plan and sectional elevation, Figs. 1347, 1348. The intervals between the wicks, which admit currents of air,

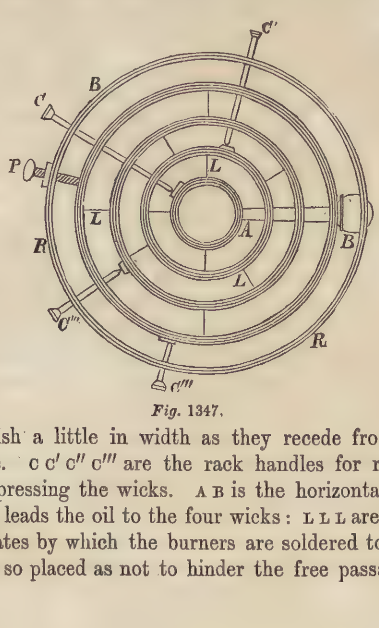


Fig. 1347.

diminish a little in width as they recede from the centre. C C′ C″ C‴ are the rack handles for raising or depressing the wicks. A B is the horizontal duct which leads the oil to the four wicks: L L L are small tin plates by which the burners are soldered to each other, so placed as not to hinder the free passage of

air: P is a clamping screw for maintaining at its proper level the gallery R R, which carries the glass

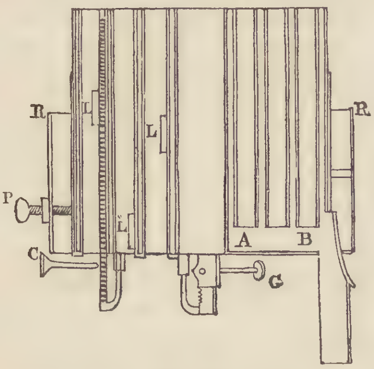


Fig. 1348.

chimney E, Fig. 1349, above which is a sheet-iron cylinder F, which serves to increase the length of the chimney, and within it is a small damper D, capable of being turned by a handle for regulating the draught; B is the pipe which conveys oil to the wicks. The excessive heat which would be produced by the concentric flames is checked by means of a superabundant supply of oil thrown up from a cistern below by a clock-work movement, and made constantly to overflow the wicks as in the mechanical lamp of Carcel. By this means the wicks are prevented from rapid carbonization, and when kept well supplied with colza oil, they have been known to maintain for 17 hours a full flame without requiring to be touched. The only risk in using such a lamp arises from the liability to occasional derangement of the leather valves, that force the oil by means of clock-work. This may lead to the extinction of the lamp; and in order to warn the keeper of so serious an accident, there is attached to the lamp an alarum, consisting of a small cup pierced in the bottom, which receives part of the overflowing oil from the wicks, and when full, balances a weight placed at the opposite end of a lever. The moment the machinery stops, the cup ceases to receive the supply of oil, and the remainder running out at the bottom, the equilibrium of the lever is destroyed, so that it falls and disengages a spring which rings a bell sufficiently loud to waken the keeper, should he happen to be asleep. Mr. Stevenson, thinking it not unlikely that this alarum might tempt the keepers to relax in their watchfulness and fall asleep, has adopted in all the lamps of the dioptric lights on the Scotch coast the converse mode of causing the bell to cease ringing when the clock-work stops. Another precaution is to have in the light-room a spare lamp trimmed and adjusted to the height for the focus, which may be lighted and substituted for the other in case of accident. The most advantageous heights for the flames in dioptric lights vary from 4·33 to 3·15 inches. The lamp-pumps should raise four times the quantity of oil actually consumed in maintaining the flame during a given time, to prevent the wick from being carbonized too quickly.

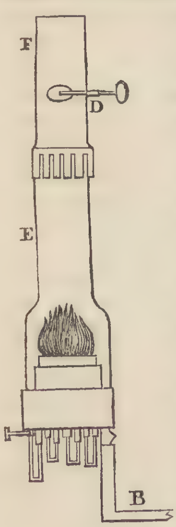


Fig. 1349.

The expense of the various parts of the Dioptric apparatus is as follows:—great lens of first order, 58*l.* (8 of which are required); pyramidal lens and mirror 14*l.* 12*s.* (8 of which are required); catadioptric cupola for 360° of horizon, 480*l.*; catadioptric rings below lenses, 360*l.*; panel of dioptric belt for fixed lights of first order, 56*l.* (of which 8 are required for the whole circle); apparatus of fourth order for a fixed light for whole horizon, 128*l.*; apparatus of sixth order for a fixed light for whole horizon, 44*l.* The expense of the mechanical lamp of the first order, with four wicks, (with framed tripod and adjusting screws as made for the Scotch lighthouses,) is 30*l.*

The dioptric lights used in France are divided into six orders, which refer to their power and range, and not to their characteristic appearances. Lights of the *first* order have an interior radius of focal distance of 36·22 inches (92 cm.), and are lighted by a lamp of four concentric wicks, consuming 570 gallons of oil per annum. Lights of the *second* order have an interior radius of 27·55 inches (70 cm.), and are lighted by a lamp of 3 concentric wicks, consuming 384 gallons of oil per annum. *Third* order: focal distance 19·68 inches: the lamp has two concentric wicks, and the annual consumption of oil is 183 gallons. *Fourth* order, or *harbour lights:* internal radius 9·84 inches: lamp with 2 wicks, consumes about 130 gallons of oil per annum. *Fifth* order: focal distance 7·28 inches. *Sixth* order: internal radius 5·9 inches. The lamp has an Argand burner, and consumes 48 gallons of oil per annum. Each order admits of certain combinations which produce various appearances, and form the distinctions used for dioptric lights. The *first* order contains—1, lights producing once every minute a great flash, preceded by a smaller one, by the revolution of 8 great lenses and 8 smaller ones, combined with 8 mirrors. 2, lights flashing once in every half minute, and composed of 16 half lenses. The subsidiary parts of such lights may be simply catoptric or diacatoptric.[1] 3, fixed lights composed of a combination of cylindric pieces with curved mirrors or catadioptric zones ranged in tiers above and below them. The *second* order comprises revolving lights with 16 or 12 lenses, which make flashes every half minute; and fixed lights varied by flashes once in every 4 minutes, an effect which is produced by the revolution of cylindric refractors with vertical axes ranged round the outside of the fixed light apparatus. The *third* order contains common fixed lights, and fixed lights varied by flashes once in every 4 minutes. The *fourth* order

(1) Mr. Stevenson refers the term *diacatoptric* to the arrangement of pyramidal lenses and plane mirrors, by which the light is first *refracted* and then *reflected*.

contains simple fixed lights, and fixed lights varied by flashes once in 3 minutes. The *fifth* order has fixed lights varied by flashes once in every 3 minutes, and fixed lights of the common period.[1] The *sixth* order contains only fixed lights. In consequence of the great loss of light resulting from the application of coloured media, distinctions based upon colour have generally been discarded in the French lights.

Having thus stated the chief characteristic features of the two systems of lights, we append a few general conclusions as to their comparative merits, referring to Mr. Stevenson's work for the facts and reasonings upon which they are based. It appears, 1st, that by placing 8 reflectors upon each face of a revolving frame a light may be obtained as brilliant as that derived from the great annular lens; and that in the case of a frame of three sides, the excess of expense by the reflecting mode would be 63*l.* 18*s.*, and in the case of a frame of 4 sides the excess would amount to 225*l.* 2d, That for burning oil economically in revolving lights which illumine every point of the horizon successively, the lens is more advantageous than the reflector in the ratio of 3·6 to 1. 3d, That the divergence of the rays from the lens being less than from the reflector, it becomes difficult to produce by lenses the appearance which characterises the catoptric revolving lights, already so well known to British mariners; hence any change of existing lights would involve some practical objections, which, however, would not apply in the case of new lights. 4th, That the uncertainty in the management of the lamp renders it more difficult to maintain the revolving dioptric lights without risk of extinction. 5th, That the extinction of one lamp in a revolving catoptric light is not only less probable, but leads to much less serious consequences than the extinction of the single lamp in a dioptric light; because in the first case, the evil is limited to diminishing the power of one face by an eighth part; while in the second, the whole horizon is totally deprived of light.

A comparison of the fixed dioptric and the fixed catoptric has led to the following summary of results: —1st, It is impossible, by any practicable combination of paraboloidal reflectors, to distribute round the horizon a zone of light of exactly equal intensity; but this may be easily effected by dioptric means. In other words, the qualities required in fixed lights cannot be so fully obtained by reflectors as by refractors. 2d, The average light produced in every azimuth by burning one gallon of oil in Argand lamps, with reflectors, is only about one-fourth of that produced by burning the same quantity in the dioptric apparatus, and the annual expenditure is 140*l.* 3*s.* 8*d.* less for the entire dioptric than for the catoptric light. 3d, The characteristic appearance of the fixed reflecting light in any one azimuth would not be changed by the adoption of the dioptric method, although its increased mean power would render it visible at a greater distance in every direction. 4th, From the equal distribution of the rays, the dioptric light would be observed at equal distances in every point of the horizon; an effect which cannot be fully attained by any practicable combination of paraboloidal reflectors. 5th, The fixed apparatus being more simple than the revolving, an accident to the mechanical lamp is sooner rectified. 6th, The extinction of a lamp in a catoptric apparatus leaves only $\frac{1}{25}$th part of the horizon without light; but the extinction of the single lamp of the dioptric arrangement deprives the whole horizon of light. 7th, In certain situations a risk arises from irregularity in the distances at which the same fixed catoptric light can be seen in the different azimuths, a defect which does not exist in the dioptric light.

It appears, therefore, that the dioptric system is in most cases to be preferred to the catoptric. It has been already stated that in the catoptric arrangement the size of the flame, and its distance from the surface of the reflector, are of great importance, and that the divergence of the resultant beam materially affects its fitness for the purpose of a lighthouse. So, also, with the lens: unless the diameter of the flame of the lamp has to the focal distance of the instrument a relation such as may cause an appreciable *horizontal* divergence of the rays refracted through it, it could not be usefully applied to a lighthouse: for, without this, the light would be in sight during so short a time that the seaman would have much difficulty in observing it. Nor must the consideration of *vertical* divergence be altogether overlooked. Although such divergence above the horizon involves a total loss of the light which escapes uselessly upwards into space, "yet if the sheet of light which reaches the most distant horizon of the lighthouse, however brilliant, were as *thin* as the absence of all vertical divergence would imply, it would be practically useless; and some measure of dispersion in the arc *below* the horizon is therefore absolutely indispensable to constitute a really useful light. In the reflector the greatest vertical divergence below the horizontal plane of the focus is 16° 8′, and that of the lens is about 4° 30′. The powerful beam of light transmitted by the lens peculiarly fits it for the great sea-lights, which are intended to warn the mariner of his approach to a distant coast which he first makes on an *over-sea* voyage; and the deficiency of its divergence, whether horizontal or vertical, is not practically felt as an inconvenience in lights of that character, which seldom require to serve the double purpose of being visible at a great distance, and at the same time of acting as guides for danger near the shore. For such purposes the lens applies the light much more advantageously, as well as more economically, than the reflector; because, while the duration of its least divergent beam is nearly equal to that of the reflector, it is *eight* times more powerful. A revolving system of 8 lenses illuminates a horizontal arc of 32° with this bright beam. The reflector, on the other hand, spreads the light over a larger arc of the horizon; and while its least divergent beam is much less powerful than that of the lens, the light which is shed

(1) The term "fixed lights varied by flashes," has been changed for "fixed lights with short eclipses," because it has been found that, at certain distances, a momentary eclipse precedes the flash.

over its *extreme* arc is so feeble as to be practically of no use in lights of extensive range, even during clear weather. When a lighthouse is placed on a very high headland, however, the deficiency of divergence in the vertical direction is often found to be productive of some practical inconvenience; but this defect may be partially remedied by giving to the lenses a slight inclination outwards from the vertical plane of the focus, so as to cause the most brilliant portion of the emergent beam to reach the visible horizon which is due to the height of the lantern. It may be observed, also, that a lantern at the height of 150 feet, which (taking into account the common height of the observer's eye at sea) commands a range of upwards of 20 English miles, is sufficient for all the ordinary purposes of the navigator, and that the intermediate space is practically easily illuminated even to within a mile of the lighthouse, by means of a slight inclination of the subsidiary mirrors, even where the light from the principal part of the apparatus passes over the seaman's head. For the purpose of leading lights, in narrow channels, on the other hand, and for the illumination of certain narrow seas, there can be no doubt that reflectors are much more suitable and convenient. In such cases, the amount of vertical divergence below the horizon forms an important element in the question, because it is absolutely necessary that the mariner should keep sight of the lights even when he is very near them; while there is not the same call for a very powerful beam which exists in the case of sea-lights. Yet, even in narrow seas, where low towers, corresponding to the extent of the range of the light, are adopted, but where it is at the same time needful to illuminate the whole, or the greater part of the horizon, the use of dioptric instruments will be found almost unavoidable, especially in fixed lights, as well from their equalizing the distribution of the light in every azimuth, as from their much greater economy in situations where a large annual expenditure would often be disproportionate to the revenue at disposal. In such places, where certain peculiarities of the situation require the combination of a light equally diffused over the greater portion of the horizon, along with a greater vertical divergence in certain azimuths than dioptric instruments afford, I have found it convenient and economical to add to the fixed refracting apparatus a single paraboloidal reflector in order to produce the desired effect, instead of adapting the whole to the more expensive plan for the sake of meeting the wants of a single narrow sector of its range. In other cases, where the whole horizon is to be illuminated and great vertical divergence is at the same time desirable, a slight elevation of the burner, at the expense, no doubt, of a small loss of light, is sometimes resorted to, and is found to produce, with good effect, the requisite depression of the emergent rays."

The oxyhydrogen, or lime light, and the Voltaic light from carbon points, have, on account of their intensity, been proposed for the purposes of the lighthouse. There is, however, considerable uncertainty in the exhibition of those lights, to say nothing of the danger of entrusting so explosive a mixture as oxygen and hydrogen to the care of the light-keepers. But there are other objections: the smallness of the flame renders them wholly inapplicable to dioptric instruments, which require a great body of flame to produce a degree of divergence sufficient to render the duration of the flash in revolving lights long enough to answer the purpose of the mariner. This defect also applies to these lights when used with the reflector, for a fixed light. The bude light, produced by combining a current of oxygen with the flame of oil, has not been found to answer in practice. Coal gas has been occasionally used in lighthouses, it being conveyed in tubes to the burners, and it has its advantages in dioptric lights: it would of course be difficult of application in the catoptric system, especially the revolving, but the risk of an explosion ought at all times to exclude this gas as a source of light to these important establishments.

In some cases it is found necessary to cut off on a given bearing the beam proceeding from a lighthouse, as a guide to the seamen to avoid some shoal, or as a hint to put about and seek the opposite side of a channel. This is sometimes done by placing a board on the outside of the light-room; or by distributing the reflectors round the concave side of the lantern, towards the land: the latter arrangement, however, is inapplicable when the illuminated sector exceeds the dark one.

The term *double lights* properly applies only to lights on different levels. They are used for the sake of distinction from other lights, and are most effective when placed in the same tower, and when the lower lantern is arranged in the form of a gallery, around the outside of the tower. *Leading lights* are lights in different towers, and their use is to indicate to the seamen a given line of direction, such as the central part of a narrow channel, by their being seen in one line; and the alternate opening of the lights on either side of their conjunction serves to indicate the proper moment for changing the tack. In other situations the line of conjunction serves as a cross-bearing to warn the mariner of his approach to some danger, or to indicate his having passed it, and thus to assure him of his entry in wider sea room.

The construction of the lighthouse lantern is a point of importance. A common defect is the vertical direction of the astragals, which thus intercept the light in the azimuth which they subtend. Mr. Stevenson has adopted a diagonal arrangement, Fig. 1350, as being better adapted for equalizing the effect of the light, and giving greater stiffness and strength to the frame-work, which is formed of gun-metal, the dome being of copper. The use of these metals avoids the necessity of painting. A lantern for a light of the first order, 12 feet in diameter, and with glass frames 10 feet high, costs about 1,260*l.* On the level of the top of the lower panes is a narrow gangway, for the keeper to stand on, in order to cleanse and wash the upper panes, an operation which,

in snowy weather, must sometimes be frequently repeated during the night.[1] At the top of the second

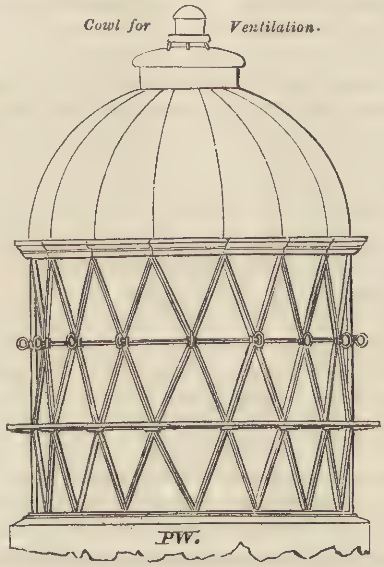


Fig. 1350. LANTERN FOR FIRST ORDER OF LIGHTS.

panes hand-rings are fastened for the security of the keepers in stormy weather. A light trap-ladder is also attached to the outside of the lantern, for affording access to the ventilator in the dome. PW is the parapet wall.

The lantern is liable to injury in high winds, or the glass may be broken by large sea-birds coming against it in a stormy night, or by small stones violently driven against it by the wind. Framed plates called *storm-panes* are kept in reserve to take the place of a broken pane.

The Northern lighthouses are each under the charge of at least two light-keepers, whose duties are to cleanse and prepare the apparatus, to mount guard singly after the light is exhibited, and to relieve each other at stated hours, fixed by the printed regulations and instructions under which they act. No keeper on watch is allowed to quit the light-room until relieved by his comrade; and means are afforded for making signals by air-tubes or otherwise from the light-room to the sleeping apartments below. In such situations as the Bell Rock, four keepers are provided for one lighthouse, one being always ashore on leave with his family, and the other three at the lighthouse. At all the land-lighthouses the services of an occasional keeper are engaged, who receives pay only while actually employed at the lighthouse. Where the situation allows of it, it is desirable to have the keeper's rooms in a building adjoining the light-tower, to avoid dust, which is so injurious to the delicate apparatus and machinery in the light-room. Covered ash-pits are likewise provided at all the dwelling houses, to prevent the dust of the fire-places from being carried by the wind to the light-room; and iron floors are used in the lighthouses instead of stone, which is often liable to abrasion. The greatest cleanliness is enforced in all that belongs to the lighthouse, especially to the light-room. The lenses and reflectors are carefully freed from dust before being washed or burnished, or they might be scratched in the cleaning. The reflectors are burnished with prepared rouge (tritoxide of iron), applied with soft chamois-skin; but the best method of keeping the reflectors clean, is by a long rubbing every day with a dry soft skin without rouge. Spirit of wine is used for cleansing the lenses and glass mirrors, a linen cloth being used for applying it, and a soft dry linen rubber for drying the glass, which is finally rubbed with a fine chamois-skin.

At the entrance of some of the great estuaries of Great Britain and Ireland, the erection of lighthouses being impossible, on account of the sand-banks being too soft to sustain a solid structure, and the water too deep to allow of the erection of a screw-pile lighthouse, *floating lights* are established. The light-vessels of the Trinity House (of which there are twenty-six on the coast of England) are moored with chain-cables of $1\frac{1}{2}$ inch diameter, and a single mushroom anchor, of 32 cwt. The lanterns are octagonal in form, $5\frac{1}{2}$ feet in diameter; and where fixed lights are exhibited, they are fitted with eight Argand lamps, each in the focus of a parabolic reflector, 12 inches in diameter. In revolving lights only four lamps and reflectors are used.

We cannot conclude this notice without expressing our obligations to Mr. Alan Stevenson for the very kind manner in which he has placed his labours at our disposal. The worthy successor to the Architect of the Bell Rock lighthouse, the founder of the Skerryvore, is not only eminent as a lighthouse engineer, but also as a lighthouse optician. To him are we indebted for a complete elucidation of the two methods of illuminating lighthouses; and should the reader be tempted by the abstracts and quotations which we have made from Mr. Stevenson's works to inquire further into the subject, we cordially refer him to the "Rudimentary Treatise on the History, Construction, and Illumination of Lighthouses," published in 1850, in Weale's Rudimentary Series.

LIGHTNING. See ELECTRICITY.

LIGNITE. See COAL.

LIME. Sir Humphry Davy discovered in 1808 that when moistened lime was rendered electro-negative in contact with mercury, an amalgam was formed, which by distillation yielded a white metal, the basis of lime. He named it *Calcium*, from *calx*, the Latin for lime. Its symbol is Ca, and its combining weight 20. When this metal is exposed to the air and gently heated, it burns and produces *oxide of calcium*, or *lime*, CaO.

The usual source of lime is one of the carbonates. By exposing powdered white marble, or Iceland spar,

(1) At some of the lighthouses of the Mediterranean, the lantern is at certain seasons so completely covered with moths as to obscure the light, and to require the attendance of men with brooms. The Editor was informed by the keepers at the Eddystone, that bees and other insects were much attracted by the light, and collected round the lantern in great numbers: larks and other birds flew against it, and becoming stunned with the blow, were picked up on the balcony, and were cooked by the men for breakfast.

to a white heat for an hour in an open crucible, lime may be obtained of tolerable purity; but to obtain it quite pure, white marble is dissolved in dilute hydrochloric acid, a little caustic ammonia added, and the solution filtered: carbonate of ammonia is next added, and the precipitate washed, dried, and exposed to a white heat in an open vessel. In a close vessel the decomposition of carbonate of lime is so imperfect that a red heat continued for many hours is insufficient to expel the carbonic acid. Bucholz found that on strongly heating five or six pounds of pure chalk closely pressed into a crucible, it was converted into a hard, foliated, yellowish mass, retaining nearly all its carbonic acid: it was semitransparent from the effect of incipient fusion. Sir James Hall had previously found that by exposing powdered chalk to great heat and pressure, it was fused without the escape of carbonic acid: in this way he supposes marble to have been formed by a natural process.

Pure lime is white, or pale grey; it is acrid and caustic, and has a powerful alkaline reaction. Its density varies from 2·3 to 3·08: it is difficult of fusion, but promotes the fusion of some other oxides in a remarkable manner, and hence its use as a flux. When heated in the flame of the oxyhydrogen blowpipe it becomes highly luminous, forming what is called the *Drummond light*, and under this intense heat it slowly volatilizes, and covers the interior of the roof of the lantern with a sublimate of lime. It is an important ingredient in mortar and other cements [see MORTAR], and in its caustic state it is in certain cases a valuable manure. When exposed to the atmosphere it first absorbs moisture and then carbonic acid, and becomes partly converted into carbonate of lime. When kept perfectly dry it does not absorb carbonic acid. Its powerful affinity for moisture renders it valuable for drying gases, and abstracting water from alcohol and some other liquids. Diffused through water it forms *cream*, or *milk of lime*. When lime is wetted with water a portion of the water combines chemically with it, while another portion passes off in vapour, and if quickly slaked in large heaps, the temperature rises to above 500°, with the evolution of light in a dark place: wood has been scorched in this way, and lime barges have been set on fire. The maximum temperature is produced when the lime is mixed with about half its weight of water. Before the water is added the lime is called *quick*, and after that addition *slaked*. It enlarges considerably in volume by the operation. This *slaked lime* is a true hydrate CaO,HO, and may be obtained in imperfect six-sided crystals by placing lime water under the receiver of an air-pump, with another vessel containing sulphuric acid to absorb the vapour as fast as it is formed. Lime is, to a small extent, soluble in water. At a temperature of 60°, 750 parts of water are required for the solution of one part of lime: by increasing the temperature less lime is dissolved, so that at 212°, 1280 parts of water are required for the solution of one part of lime; while by diminishing the temperature the solvent power of water is increased; for at 32° only 656 parts of water are required for the solution of one part of lime. Lime water is limpid and colourless; its taste nauseous and alkaline, and its alkaline reaction very decided. It powerfully reddens turmeric, and changes the blue of violets and cabbage to green. It is used in medicine as an antacid. It is easily prepared by pouring warm water upon powdered lime, and when the mixture has cooled in a close vessel and subsided, the clear part is decanted off. Exposed to the air, a pellicle of carbonate of lime forms upon its surface, which, if broken, is succeeded by another pellicle, until the whole of the lime is separated from the solution in the form of an insoluble carbonate.

Calcium, or its oxide, forms numerous compounds with other bodies, only a few of which can be noticed here. *Chloride of calcium*, or *muriate of lime*, $CaCl$, is found in sea-water, and in some mineral waters. It may be formed by heating lime in chlorine, when oxygen is evolved equal in volume to half that of the chlorine absorbed. It may also be formed by the action of hydrochloric acid on carbonate of lime, evaporating to dryness, and exposing the residue to a red heat in a close vessel. It has a strong attraction for water, and soon deliquesces by exposure to the air; hence its use in drying gases, and in depriving alcohol, ether, and other liquids of water by distilling them off dry chloride of calcium. One part of water at 60° dissolves four parts of the chloride; at 212°, water dissolves it readily: it is also very soluble in alcohol. It becomes phosphorescent by fusion, forming what is called *Homberg's phosphorus*.

Chloride of lime or *bleaching powder* is noticed under BLEACHING.

Calcium forms compounds with Iodine, Bromine, and Fluorine. The native *fluoride of calcium* is noticed under FLUOR-SPAR.

Nitrate of lime, CaO,NO_5, is a deliquescent salt soluble in one-fourth its weight of water at 60°. It is sometimes found in spring water, in old plaster, and in artificial nitre-beds. [See POTASH.]

Calcium forms with sulphur a number of compounds, such as the *sulphuret*, CaS, the *bisulphuret*, CaS_2, and others. *Hyposulphite of lime*, CaO, S_2O_2, is abundantly produced from the refuse lime of the gas-works. After having been removed from the purifier and exposed to the air for a few days until it ceases to smell of sulphuretted hydrogen, the hyposulphite may be dissolved out by an equal weight of cold water, and crystallized after evaporation at 120°; or by means of carbonate of soda it may be converted into hyposulphite of soda. The lime salt is used for removing the salts of silver from photogenic drawings, so as to render them permanent when exposed to light. [See PHOTOGRAPHY.]

Sulphite of lime, CaO,SO_2, and *hyposulphite of lime*, CaO,S_2O_5, are of no importance in the arts, but *sulphate of lime*, CaO,SO_3, under its various names of *selenite*, *alabaster*, *gypsum*, *plaster-stone*, &c., is a compound of firstrate importance in the arts. [See GYPSUM.] It may be formed artificially by dropping sulphuric acid upon lime, or by decomposing a solution of chloride of calcium, or any of the soluble salts of

lime, by sulphuric acid or by a soluble sulphate. The sp. gr. of artificial anhydrous sulphate of lime is 2·927: it requires about 500 parts of water at 60°, and 450 parts at 212°, for its solution: but according to Berzelius it is equally soluble in hot or cold water. Most spring and river waters contain traces of this salt, and in *hard* waters it is often abundant, rendering them slightly nauseous and unfit for washing and for culinary purposes. It resembles other sulphuric salts in slowly decomposing when the solution is subject to the action of decaying vegetable matter, in which case the odour of sulphuretted hydrogen is evident. It is also decomposed by the alkaline carbonates.

Phosphuret of Calcium, CaP, is formed by passing the vapour of phosphorus over lime, heated to a dull redness, under which circumstances the oxygen of the lime converts a portion of the phosphorus into phosphoric acid, and the evolved calcium combines with another portion of phosphorus to form phosphuret of calcium. It is a dull brown compound; when thrown into water it rapidly decomposes a portion of it with the evolution of phosphuretted hydrogen gas, the bubbles of which, escaping at the surface, ignite by coming in contact with the oxygen of the air. *Hypophosphite of lime*, CaO,PO,2HO, and *phosphite of lime*, are not of importance; but the phosphates, of which there are several, are very much so. The common *phosphate of lime, tribasic phosphate*, or *bone-phosphate*, occurs abundantly in bone-ash, and is also found with fluoride of calcium in *apatite* and *moroxite*. A solution of bone-earth in hydrochloric or nitric acid, is boiled to expel the carbonic acid; and precipitated by caustic ammonia, the pure bone phosphate separates as a bulky precipitate, which forms in drying a white amorphous mass, and consists of three equivalents of lime, or 53·84 per cent., and one equivalent of phosphoric acid, or 46·16 per cent. It occurs native in apatite and moroxite, as already noticed; these phosphoresce when heated; and it also occurs in *phosphorite* and *asparagus stone*. Its primitive form is a six-sided prism. Crystallized apatite is found in great beauty in Cornwall and Devon. *Coprolites* abound in phosphate of lime; they appear to be the excrements of fossil reptiles, and resemble in external form oblong pebbles, from 2 to 4 inches in length, and 1 or 2 in diameter; but they vary in size with the calibre of the intestines which produced them: their usual colour is ash-grey interspersed with black; their texture resembles indurated clay; they have a conchoidal and glossy fracture, and the scales, and occasionally the teeth and bones of fishes, are irregularly dispersed through them. They are abundant on the shore at Lyme Regis, in the lias of the estuary of the Severn, and in the gault of Surrey; but they occur throughout the lias of England, and in strata of all ages that contain the remains of carnivorous reptiles. Attempts have been made to use these nodules in the production of phosphorus, and also as a manure; they contain from 55 to 70 per cent. of bone phosphate. Some varieties of chalk contain small quantities of phosphate of lime: it is found in some schistous and other rocks; it is present in all fertile soils, and in the vegetables which they produce, and in this way it is conveyed into the animals which feed upon them. Graham has detected in the water of the deep wells of London minute quantities of phosphate of lime and phosphate of iron; he was induced to look for it from the rapid growth of confervæ, and thinks it probable that the superiority of certain waters for irrigation may depend upon the presence of phosphoric acid. The other phosphates of lime need not detain us here.

The most abundant compound of lime is the *carbonate*, CaO,CO_2. It is found in spring and river, and consequently in sea-water. It is an essential ingredient in all fertile soils, and it occurs in every kind of rock. The primitive form of crystallized carbonate of lime, or *calcareous spar*, is an obtuse rhomboid, and its secondary forms are more numerous than those of any other substance, as many as 680 modifications having been described and figured. *Iceland spar* is extremely pure carbonate of lime in its primitive form; it is doubly refractive when transparent, but some of the varieties are opaque or translucent, snow-white or tinged with different colours; its fracture is foliated and rhomboidal; it is scratched by fluor-spar; it dissolves with effervescence in hydrochloric acid, and the solution, much diluted, gives a white precipitate with oxalate of ammonia. Syrup of sugar dissolves hydrate of lime, and crystals of the carbonate may be thus obtained, by boiling 1 part hydrate of lime, 3 of sugar, and 6 of water, filtering and exposing to air for a couple of weeks. The lime is deposited in acute rhombic crystals. Pure water does not dissolve any sensible quantity of carbonate of lime; but water containing carbonic acid takes up a notable quantity. On this account the waters of many natural sources contain carbonate of lime, and when by exposure to air carbonic acid escapes, the carbonate of lime separates, and forms upon solid substances, near, or placed there for the purpose, calcareous incrustations, often of considerable size: the *petrifying-well* at Matlock owes its peculiar properties to this cause. Calcareous *stalactites* and *stalagmites* are produced from a similar cause in some of the caverns of Derbyshire and elsewhere. The waters traversing crevices in the rocks fall in drops from the vault of the cavern; but each drop before falling remains suspended for a time, during which, a portion of its carbonic acid escapes, and a minute portion of its carbonate of lime is left behind. It also deposits another minute portion of calcareous matter on the spot upon which it falls, and as the drops are formed nearly in the same spot for years together, a calcareous incrustation is thus produced, hanging downwards from the roof, and slowly increasing in size by the action of successive drops. In this way a stalactite is formed (σταλάζω, *I drop*). Immediately below this incrustation another is formed, and in this way a stalagmite is formed (σταλαγμὰ, *a drop*); and in process of time the two incrustations unite, and form a continuous column. See Fig. 1351.

Satin-spar is a fibrous variety of carbonate of lime

Arragonite, originally from Arragon in Spain, often occurs in six-sided crystals, of a reddish colour, and harder than the common carbonate. An acicular or fibrous variety is found in France and Germany: *flos ferri* is regarded as belonging to the same species. Some varieties contain about 3 per cent. of strontia.

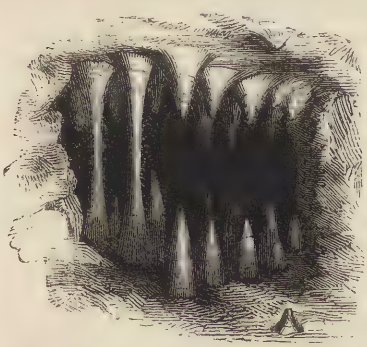


Fig. 1351. STALACTITES & STALAGMITES.

The various calcareous rocks which are met with among all the sedimentary deposits, often form strata of enormous thickness, and afford carbonate of lime of various degrees of compactness, and many of these contain fossil remains of great extent, variety, and beauty. The numerous varieties of *marble* and limestone consist essentially of carbonate of lime. [See MARBLE.] There are many varieties of the inferior limestone, such as *common marble, bituminous limestone*, also called *swine-stone* or *stink-stone*, from its peculiar smell when rubbed: *oolite* or *roestone*, a common building stone at Bath; and its variety, *Portland stone: Pisolite* or *pea-stone*, consisting of small rounded masses in concentric layers with a grain of sand in the centre; and lastly, *chalk* and *marl*. All these stones are used for ornamental or useful purposes; in building, in agriculture, and in the formation of mortars and cements. The subject of *lime-burning* will be treated of in the article MORTAR.

The shells of molluscous and other animals, the egg-shells of birds, the hard casing of the lobster and crab, are formed of carbonate of lime almost pure: the bones of animals also contain a considerable quantity of it.

The general characters of the salts of lime are as follows:—those which are soluble in water are not precipitated by pure ammonia, but potash and soda throw down hydrate of lime, and the carbonates of potash, soda and ammonia produce precipitates of carbonate of lime. Oxalate of ammonia produces in their solutions a white precipitate of oxalate of lime soluble in nitric and hydrochloric acids. This test is extremely delicate. The soluble sulphates throw down sulphate of lime. Those salts of lime which are soluble in alcohol, tinge the edge of its flame of a reddish colour; and those salts which are insoluble in water are decomposed by boiling with carbonate of potash, and afford carbonate of lime; they are usually soluble in nitric and hydrochloric acids.

LIME-KILN. See MORTAR.

LIME-STONE. See LIME—MARBLE.—INTRODUCTORY ESSAY, p. lxxxiii.

LINE. A line is defined by Euclid as "length without breadth."

LINE. Before the metrical system was adopted in France, the inch was divided into 12 lines, and the line into 12 points. We sometimes see the English inch divided into lines. The French line is ·0888 of an English inch, and also $2\frac{1}{4}$ millimetres.

LINEN. See FLAX—WEAVING.

LINSEED OIL. See OILS.

LIQUATION. See ELIQUATION—ASSAYING. Also INTRODUCTORY ESSAY, p. xcii, where a liquation furnace is represented.

LIQUEUR, the French name for a liquor compounded of alcohol, water, sugar and some aromatic substance. The number of liqueurs is very great: they are sometimes named after the inventor.

LIQUID. See COHESION—ADHESION—HYDROSTATICS and HYDRAULICS.

LIQUIDAMBAR (from *liquidum*, fluid, and *ambar*, the Arabic name of amber), a balsam obtained from the *Liquidambar Styraciflua*, a tree growing in Mexico, Louisiana, and Virginia. See BALSAMS.

LIQUORICE. An extract prepared from the root or *rhizoma* [1] of the *Glycyrhiza glabra*, a native of Germany, but cultivated in some parts of Britain. The extract is chiefly prepared in Spain, and is imported under the name of *Spanish juice*, or *liquorice*. The rhizoma is taken up at the age of 3 years. It is often several feet in length and about half an inch thick. It has a faint odour and a sweet mawkish taste: if the bark be chewed it becomes in a short time acrid, from the presence of a resin. On evaporating a strong infusion to a small bulk, and adding sulphuric acid, a precipitate falls containing sugar and albumen: this is washed with water acidulated with sulphuric acid, then with pure water, and afterwards digested in alcohol, which separates the albumen. A solution of carbonate of potash is then dropped into the alcoholic solution until the acid is neutralized. It is filtered and evaporated, and a yellow transparent mass of *liquorice sugar* (*Glycyrhizine*) is thus obtained. It is intensely sweet, uncrystallizable and easily soluble in alcohol and in water: it combines with acids, bases, and salts. Its composition is expressed by $C_{16}\ H_{12}\ O_{12}$.

The rhizoma by infusion in warm water or maceration in cold, affords a mucilaginous fluid which is bland and demulcent. The powdered root is used to prevent recently made pills from adhering. The extract is formed into rolls 6 or 8 inches long, which are dried and wrapped in bay leaves to prevent them from adhering. 100 lbs. of the dried root afford 30 lbs. of extract. Starch or peasmeal is usually added in making up the rolls, the object being to prevent them from melting, which they have a tendency to do in warm weather. The rolls should be black, dry, and in cold weather break easily with a shining fracture. Liquorice, when pure, dissolves entirely in the mouth. Crude liquorice not only contains starch or meal, but also copper or brass derived from the pans used in boiling down the infusion: hence the necessity fort *refining*, an operation which is performed by melting the rolls in water, draining off the solution so as to leave sand and other impurities behind, inspissating

(1) A long creeping subterraneous stem, from ῥίζωμα, a *root*.

it and forming it into more slender cylinders, sugar or gum Arabic being added to produce hardness. In Yorkshire the extract is prepared in the form of small cakes or wafers, named *Pontefract cakes.* Liquorice is used as a demulcent to allay tickling cough.

LITHARGE. See LEAD.

LITHIC ACID, also called *Uric acid* and *Urylic acid.* It was discovered by Scheele in urinary calculi, whence the term lithic acid (from λίθος, a *stone*). It has been found in the urine of animals, in guano, in the coprolites or fossil excrement of Ichthyosauri, in the excrement of snakes, &c. It is a soft, white, crystalline powder, almost insoluble in cold water. It forms salts with bases. Its formula is $C_{10}\,H_4\,O_6\,N_4$.

LITHIUM, a metal, (L 7) the oxide of which was discovered by Arfwedson in 1817, and called *lithia,* from λίθος, a stone, from its occurring only in the mineral kingdom. It was first found in *petalite* and *spodumine,* minerals found in the iron mine of Uto, in Sweden, and it has since been found in *amblygonite* and *lepidolite,* in some varieties of *mica,* and in *green tourmaline.* Davy obtained the metal from its oxide by the action of voltaic electricity; it resembled sodium in its whiteness, but it combined so eagerly with oxygen, that its properties could not be examined. The oxide is earthy or alkaline in its character: it is white, very caustic, and saturates acids readily, and forms neutral salts with them. It attracts moisture and carbonic acid by exposure to air, and has a very strong affinity for water. It has a remarkable corrosive action upon platinum.

LITHOGRAPHY. See ENGRAVING.

LITMUS, a blue fugitive colour prepared from a lichen (*Lecanora tartarea*) growing in the Canary and Cape Verd Islands. The dye is prepared in Holland by a process similar to that used in the preparation of Archil and Cudbear. [See ARCHIL.] The ground lichens are first treated with urine containing a little potash, and left to ferment, whereby a purple-red is produced. The coloured liquor treated with quick-lime and more urine, is again left to ferment for two or three weeks: it is then mixed with chalk or gypsum into a paste, formed into small cubical lumps, and dried in the shade.

The colouring matter of litmus has been named *erythrine, erythryline,* and *erythric acid,* and is closely related to *lecanorine* ($C_{18}\,H^8\,O_8 + HO$) existing in different species of *lecanora.* It is soluble in water and in spirits of wine, and was formerly used as the colouring matter for tinging the spirit in thermometer tubes; but being liable to fade, it is no longer used for that purpose. Nollet found that the coloured spirit bleached by exposure to light, resumed its colour on breaking the tube; this occurred several times in succession. Litmus is used for staining marble: the colour sinks deep, but it renders the marble somewhat more brittle.

Litmus is used by the chemist as a test for detecting the presence of acids, which turn it red. The blue colour is restored by alkalies, so that when slightly reddened, it may also be employed to detect alkalies. For these purposes, it may be employed as a tincture, or paper stained blue, with an aqueous solution, may be used.[1] The paper should be bibulous, in strips, and not sized, so that fluid dropped upon it may be instantly absorbed. "The litmus solution should be poured into a dish or soup-plate, and the paper should be drawn through it piece by piece in such a manner that the fluid may be in contact with both sides, and then having been held to drain a few seconds, it should be hung on lines of thread or twine to dry in a convenient place. No fumes of acid or burning charcoal should have access to it, for they injure the colour; and as soon as the paper is dry, it should be taken down and laid together. The tint ought to be a full blue, or if light, not faint or undecided. It may be judged of by touching a piece of the paper with a very weak acid, and observing whether the red colour produced is vivid, and a strong contrast to the blue tint of the rest of the paper. If the solution should have been made so dilute as to produce too weak a tint, the paper may be dipped a second time, but this is to be avoided if possible, as it involves a second exposure to the air." When the paper is dry, it should be packed in a case to preserve it from light and air; the former destroys its colour, and the carbonic acid and other substances in air injure it, and even change it to red.

The solution of litmus is sometimes improperly called *tincture of turnsole,* a name which was given to the colour, in order to keep its true source a secret. *Lackmus* is the German term for litmus.

LIXIVIATION, the process of separating a soluble from an insoluble body by washing. It is described under DECOCTION.

LIXIVIUM, a term used by the older chemists to signify a solution of an alkali in water: it is synonymous with *ley.*

LOADSTONE, a term applied to the magnetic iron ore, or natural magnet, from an early observation of its most useful directive property by various nations. Thus the Chinese term it *tchu-chy,* or the *directing*-stone. In Sweden it is named *segel-stein,* or the *seeing*-stone. In Icelandic *leiderstein,* or the *leading*-stone, from the Saxon *lædan* to *lead,* whence the English name *load* or *lodestone.* So also the term *lodestar* or *guiding*-star, is applied to the star of the pole, and the term *lode* to the *leading* vein in a mine.

LOAM, a native clay mixed with quartz, sand, and iron-ochre, and sometimes with carbonate of lime.

LOCK, an instrument for securing a door, drawers, box or desk cover, &c., by means of an interior *bolt* which cannot or ought not to be capable of being moved, except by the application of a *key* or lever, applied to it from without. In some locks, however, the bolt is moved or *shot* by the action of a spring, and can be drawn back by means of a handle attached to the inner side of the lock, or by a key applied on the outside. Such are called *spring-locks* or *latch-locks.* Some locks are furnished with a couple of bolts, one of which is moved by a key and the other by a spring and handle. Others have two or more

(1) Minute directions for the preparation and use of test papers are given by Dr. Faraday in his "Chemical Manipulation."

bolts, which are shot by the action of the key alone. Locks also differ in form and size, and in the arrangement of their parts, to adapt them to the almost endless purposes to which they are applicable. In locks of the same size and constructed by the same maker on the same principle, the interior arrangements must be so varied that one key may not open more than one lock. Door and closet locks are attached to the inner surface of the door, or they are inserted into a mortice cut in the thickness of the wood, and the bolt is shot into a fixed socket. In some kinds of box and cabinet locks the bolt is shot into or through a staple, which drops into the lock on shutting the lid or cover, to which the staple is attached. The bolts are in some cases of a hooked shape, and are projected by a lateral movement into cavities prepared for them. Padlocks are detached locks, in which one end of a curved bar of iron moves on a pivot on one side of the lock, and is secured by the bolt passing through a staple at the other end of the curved bar.

In the most common variety of locks the principle of security is the insertion of *wheels* or *wards*, so arranged as to prevent the entrance or revolution of any lever or key which is not formed with corresponding openings so as to thread its way among them. The wards are usually segments of circles arranged concentrically: they are commonly formed of thin sheet iron riveted to the plates of the lock, or for damp situations they are of sheet copper to prevent rust. The better kind of warded locks have what are called *solid wards:* they are thicker than the ordinary ones, and are formed by casting in brass, and finishing in the lathe. Fig. 1352 represents a portion of the interior of a common lock; the shaded part is the back plate with two wards attached to it: the key is also shown upon the central pin secured to the plate. Now it is evident that the notches in the key must be so formed as to allow the projecting wards to pass freely into them, or the key could not turn round so as to shoot the bolt, and that a false key, not provided with notches of the same dimensions, and the same distance apart, could not under ordinary circumstances open such a lock. Wards are sometimes what are called L-*shaped*, T-*shaped* and Z-*shaped*, from the resemblance of their vertical sections to those letters. The keys to locks so fitted must of course be cut to correspond to them.

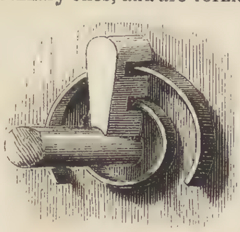


Fig. 1352.

A key is so familiar an object that it scarcely requires description; yet there are many points connected with it which deserve to be stated. The key consists of a cylindrical shank with a loop-shaped handle at one end, and a piece called the *bit* or *wet* projecting from it at or near the other. Locks which are entered from one side only have the keys with hollow shanks for the purpose of fitting the central pin; but in locks which open on either side there can be no such pin, and consequently the keys have solid shanks, (See Fig. 1354, No. 8,) and for the purpose of steadying the key the shank is prolonged beyond the bit, so as to enter and turn in a socket in the upper part of the key-hole of that plate of the lock which is furthest from the person using the key. The bit having been introduced into the body of the lock by a narrow opening or *key-hole*, is turned round within the lock by a rotatory motion imparted to the shank until it comes in contact with a part of the bolt, so shaped that the bit of the key cannot pass it to complete its revolution without shooting the bolt either backwards or forwards. The bits and consequently the key-holes are variously shaped, in order to prevent the introduction of a false key. In Fig. 1353, the bits *a b c d* are all of different shapes; *e* and *f* resemble

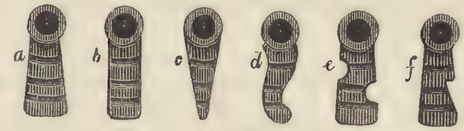


Fig. 1353.

a, but the portions cut away allow the key-hole to be so contracted in those parts as to prevent the insertion of another key not so indented.

There is, however, one great defect in warded locks, which belongs to the very principle of their construction, namely, that a key may be perfectly efficient and yet not thread the various mazes of the wards. The keys Nos. 1, 2, 3, in Fig. 1354, are of very different pattern; the first of the three has two plain or simple

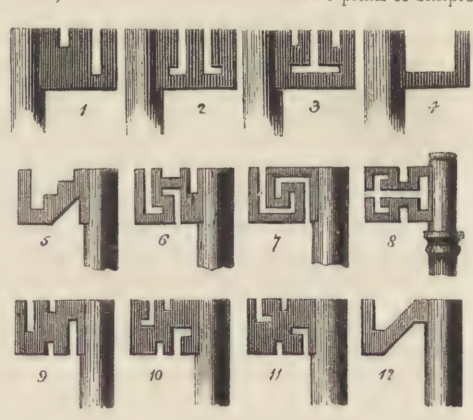


Fig. 1354.

wards; the second two L-wards, and the third a T-ward between two plain wards, and it is true that not one of these three keys could be substituted for the other in opening the locks to which they respectively belong; but unfortunately the only efficient part in these keys and in keys of a far more complicated pattern, is the extremity of the bit shown in the fourth or *skeleton-key*, which will effectually open such locks as the first three keys are intended for, without touching the wards. The lock is made a little more secure by attaching wards to the front as well as to the back plate of the lock, in which case

the key must be furnished with corresponding notches, as in No. 5. This is the key to a solid warded lock, but it is evident that a simple pick similar to No. 12 would open such a lock. Indeed the theory of *master-keys* is founded upon defects in the construction of locks such as we are now noticing. For example, the wards of the locks represented by the three keys Nos. 9, 10, and 11 are so far different from each other that one of the three keys could not be substituted for another, and yet the fourth or *master-key*, No. 12, would open all three, and indeed a whole *suit* of locks constructed on the same principle. A celebrated London lock-maker states that his keys "are made in series, having a separate and different key to each, and a master-key for opening any number that may be required. So extensive are the combinations, that it would be quite practicable to make locks for all the doors of all the houses in London, with a distinct and different key for each lock, and yet that there should be one master-key to pass the whole." No. 6 represents a very good form of wards, and No. 7, a still better form; but keys of this kind are necessarily very weak, and a little rough usage, and often ordinary wear and tear, will cause such keys to bend or break. A key of a complicated pattern does not, however, always imply a complex arrangement of wards; for the bits of many keys have more notches than there are wards to be threaded; and thousands of locks are manufactured every year with no wards at all, although the keys which accompany such locks are cut so as to represent very intricate wards.

It will be seen that all the keys hitherto figured, except No. 8, are pipe-keys, adapted to such locks as have a central pin, and consequently can be opened on one side only, and in such cases, it is evidently of little consequence whether the wards be arranged symmetrically or not. But the key No. 8 will open the lock from either side, and is symmetrical, or rather it may be regarded as two keys separated by the central opening in the bit, so that in opening the door on one side the upper half only threads the wards, and in opening the door on the other side the lower half threads the wards. In such a case, the wards on one plate are exact counterparts of those on the other plate, or there is a central plate adapted to the central opening of the key, and on either side of this plate the wards are arranged.

The form and position of the wards of an ordinary lock may be easily detected by the common artifice of the burglar, as in the warded lock represented in Fig. 1355, which, according to Mr. Chubb,[1] was once on the door of the strong-room of a London banking house. The wards of the lock will be seen concentric with the central pin. *a* is the key with the cuts in the web exactly corresponding to the wards in the lock. *b* is a burglar's instrument made of tin, with a composition of wax and yellow soap on one side of the bit, so that when inserted into the key-hole a perfect impression of the wards is taken. Now we have already seen that, in order to make a pick-lock, all that is necessary is to preserve the end of the web

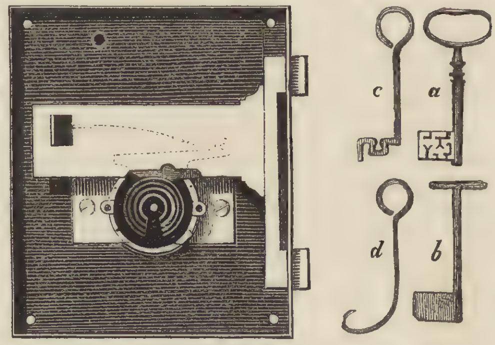


Fig. 1355.

which moves the bolt; this is accomplished by the instrument *c*, which is made so as to escape the wards, and will open or shut the lock as well as the original key. Even so rude a pick-lock as *d*, by passing round the wards, has been known to open such a lock with the greatest ease.

The second principle of security in locks is the introduction of *tumblers*. A tumbler is a sort of *spring-latch*, which detains the bolt of the lock so as to prevent its motion, until the key in turning first lifts the tumbler out of contact with the bolt, before moving it.

It is remarkable, that the security offered by tumblers is much more ancient than that by wards. Denon, in the celebrated French work on Egypt, represents a lock in common use in Egypt and Turkey at the present day, and its great antiquity is proved by the fact of its being sculptured among the bas-reliefs in the temple of Karnak. The construction of this lock will be understood from the following figures: *a a* is the case screwed to the door; *b b* is

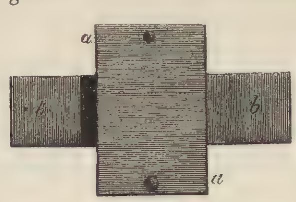


Fig. 1356.

Fig. 1358.

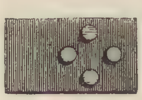


Fig. 1359.

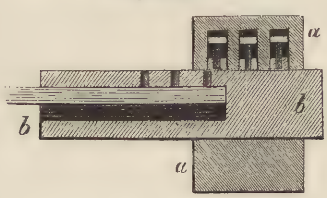


Fig. 1357.

the bolt. In the case above the bolt are a number of small cells containing headed pins, arranged in any desired form. In the top of the bolt a number of holes are similarly arranged, so that when brought into the right position, the ends of the headed pins may drop into the corresponding holes in the bolt, in which state the bolt is fastened. To unlock it, a large hollow or cavity is made at the

(1) "On the Construction of Locks and Keys, by John Chubb, Assoc. Inst. C. E. Excerpt Minutes of Proceedings of the Institution of Civil Engineers." 1850. The original lock, key, and picklocks were exhibited to the meeting, and also a few picks selected from about a ton weight of such instruments captured by the police, and deposited in Scotland Yard.

exposed end of the bolt which extends under the holes occupied by the pins. The key consists of a piece of wood, Figs. 1358, 1359, having pins arranged like those in the lock, and as long as the thickness of the bolt above the cavity. When, therefore, the key is introduced and pressed upwards, its pins exactly fill the holes in the bolt, and of course dislodge those which had fallen from the upper part of the case. The bolt may consequently be drawn as in Fig. 1357, leaving the headed pins elevated in their cells instead of occupying the position shown by the dotted lines in Fig. 1356. In Fig. 1357, the key is shown in its place, diminishing, therefore, the apparent size of the cavity in the bolt, which of course must be high enough to receive the key and its pins before the latter are lifted into the holes.

The Egyptian lock is rather widely distributed. It has been in common use from time immemorial in Cornwall and the Faro Islands, to which places it was probably taken by the Phœnicians. A similar lock is in use in the Highlands of Scotland, and the locks and keys of metal found in British towns occupied by the Romans were probably Celtic. Locks were found in Herculaneum of great apparent complexity. The earliest notice of locks is in the Odyssey (xxi.) where it is stated, that Penelope wanting to open a wardrobe took a brass key, very crooked, hafted with ivory. Before the invention of locks and keys, or in places where they were unknown, doors were fastened with knots according to fancy, and the secret of untying them was carefully preserved by the owner.

The *letter-lock* or *combination padlock*, is described in a book printed at Amsterdam in 1682. It can be easily picked. Some locks have an alarum attached to them, such as a large bell, a species of fire-arm, &c., so that an attempt to violate the lock would cause great noise and confusion. These and various other contrivances are more curious than useful, and may be passed over here.

The principle of security indicated by the above arrangement was not known in Europe till it was re-invented by Mr. Barron, and applied by him in conjunction with wards, in the construction of a lock which was patented in 1774. The same principle was adopted by Mr. Bramah about ten years later, but the use of wards or obstacles to the key was dispensed with. In the Egyptian lock, the number and position of the impediments afford security; in Bramah's lock security depends on the various degrees of motion which the several impediments require before the bolt can be moved.

Figs. 1360 and 1361 will show at a glance the difference between a warded and a tumbler lock, and the means by which in either case the bolt is kept steadily in the position in which it is left by the key. Fig. 1360 represents what is called a *back-spring* lock: the bolt *b* is represented as being *half shot*, or half locked, and can be moved either backwards or forwards by the action of the bit of the key within the large cavity of the bolt. At the top of the bolt is a spring *s*, formed by cutting a strip of metal from the bolt itself, and bending it so that its upward pressure causes the bolt to press upon the edge of the rim. When entirely locked or unlocked, one of the notches, *n* or *n′*, falls into the edge of the rim and holds the bolt: when half locked, as in the figure, the convex surface between the two notches rests upon the edge. Thus the action of the spring *s* is to hold the bolt pretty firmly in its place as left by the key; but there is this serious defect to this lock, that the bolt can be moved backwards or forwards simply by applying pressure to either end of it, so that except for the *moral purposes* of a lock, this one is of little or no use. Indeed, if the reader examines the question more closely than we intend to do in this article, he will be forced to admit that a lock, even by one of the first-rate makers, is in most cases rather a moral than a physical security. Every one, except the thief, who finds a door or a receptacle locked, is reminded by that circumstance that the owner wishes no one to open or gain entrance thereto. If the dexterous thief could only get to the lock of the iron safe, he would be able, in most cases, to pick it with ease; if he could get to the cash-box, he would carry it off without stopping to pick it. The stories that are told of skilful thieves having been baffled by the locks of such or such a maker, belong to a past era. The thieves have, within the last year or two, graduated higher in their art, and it behoves the lock-makers to follow their example. The fact is, that we trust more to our bolts than to our locks; we trust to the integrity of our servants, the watchfulness of our police, and the local ignorance of the thief.

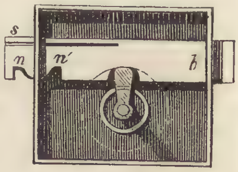


Fig. 1360.

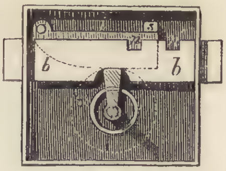


Fig. 1361.

A common tumbler lock is shown in Fig. 1361. It will be seen that, instead of the spring attached to the bolt, as in Fig. 1360, this bolt is furnished with two notches *n n′* in its upper edge. Behind the bolt *b* is the spring-latch or tumbler *i*, moving on a pivot at one end, and pressed down by the action of a spring on its upper edge. The portion of the tumbler concealed by the bolt is represented by the dotted line. At the upper angle of the tumbler is fixed a projecting stud, or *stump s*, which, when the bolt is fully shot, falls into the notch *n*, and holds it, until by the application of the key, the bit of which touches the lower edge of the tumbler, the stump is raised out of the notch, the bolt is then released, and can be shot further forward until the notch *n′* comes under the stump, which falls in and secures the bolt. Hence it will be evident that, whether the bolt be shot or unshot, no pressure applied to its extremity will move it.

Thus it will be seen that the two principles of security in locks, viz. *wards* and *tumblers*, which may be applied separately or combined, are intended to perform the same office. Wards are fixed obstructions,—tum-

blers are movable ones; and their office is to prevent the introduction of other instruments than the proper key. One of the most celebrated forms of tumbler lock is Mr. Chubb's, shown in Fig. 1362. It consists

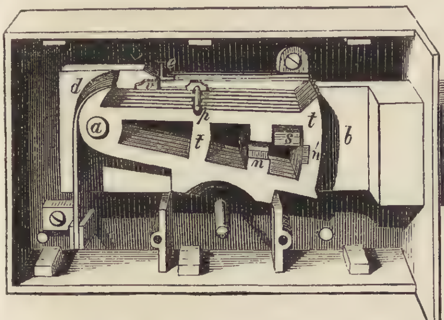


Fig. 1362. CHUBB'S DETECTOR LOCK.

of 6 separate and distinct double acting tumblers, with the addition of a *detector*, by which if, in an attempt to pick or open the lock by a false key, any one of the tumblers be lifted too high, such an attempt is discovered on the next application of the true key. The principal parts of this lock are represented in Fig. 1362. *b* is the bolt into which is riveted the stump *s*; *t* are the tumblers, 6 in number, moving on the centre pin *a;* they are placed one over the other, but perfectly separate and distinct, so as to allow of their being elevated to different heights. *d* is a divided spring, forming 6 separate springs pressing upon the ends of the 6 tumblers. *e* is the detector-spring; and it will be noticed that the back tumbler has a projecting piece near the detector-spring, with a stud or pin *p* fixed into it. Fig. 1363 is the key. Now it is evident that all the tumblers must be lifted to the exact heights required, to allow the stump *s* to pass through the longitudinal slits of the tumblers, so that the bolt may be withdrawn. There are no ordinary means of ascertaining when any one tumbler is lifted too high or not high enough, and it is still more difficult to ascertain the combination of the six. Should a false key be inserted, and any one of the tumblers be raised beyond its proper position, the detector-spring *e* will catch the back tumbler, and retain it, so as to prevent the bolt from passing, and upon the next application of the true key, notice will be given of a tumbler having been overlifted in the attempt to pick the lock, as the true key will not at once unlock it; but by turning the key the reverse way, as in locking, the tumblers will be brought to their proper bearing, allowing the bolt to move forward, and the stump to enter the notches *n'*. The bevelled part of the bolt will then lift up the detector-spring, and allow the back tumbler to fall into its place. The lock being now restored to its original position, may be opened and shut in the ordinary manner. Although the pin *p* is attached to the back tumbler only, yet as it extends across all the others, should any one be raised too high, it would elevate this pin sufficiently to catch into the detector-spring, in which case the detector would have to be relieved before any further attempt to pick the lock could be successful. Referring to the key, Fig. 1363, it may be stated as a general rule, that in locks of this construction, the lowest step, or that next to the end of the key, operates upon the bolt; the other steps move the tumblers to the exact height necessary for the stump to pass. It is evident, that by varying the length of these steps almost endless varieties of lock will be produced.

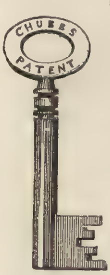


Fig. 1363.

But, perhaps, the lock which has excited most attention, admiration, and inquiry in this country, is that by Bramah, which during many years maintained its reputation. Many a mechanical genius has stood with admiring gaze before the shop-window in Piccadilly, and read the challenge appended to the pattern lock, offering a reward of 200 guineas to any artist who could construct an instrument capable of picking it; and the difficulty of the attempt will, we think, be best appreciated by the reader's making himself master of the details of the lock, which we now proceed to give.

In a pamphlet published by Mr. Bramah,[1] a simple illustration of the principle of his lock is given, which we will repeat before describing the lock itself. In Fig. 1364, B is a bolt capable under certain conditions of being moved backwards and forwards in the rectangular frame F F. In this bolt are cut 6 notches, into which are exactly fitted the 6 slides *a b c d e f*, and it will be evident, that in the present position of these slides, the bolt is incapable of moving. These slides admit of an up and down motion in the notches of the bolt B, and they are moreover furnished

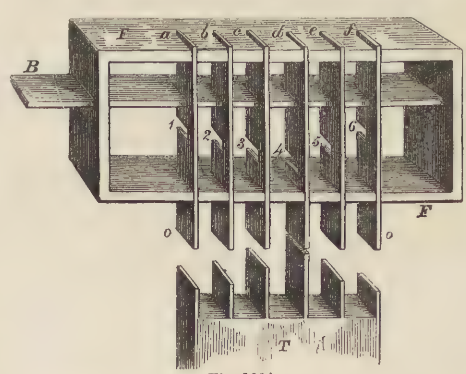


Fig. 1364.

with notches, 1, 2, 3, 4, 5, 6. Now, if by any means the slides could be raised, so that all their notches should coincide with the bolt, it is clear that in such

(1) This pamphlet is now scarce, but Mr. Hobbs has favoured us with the loan of his copy. It is entitled, "A Dissertation on the Construction of Locks; containing, *First*,—Reasons and observations, demonstrating all locks which depend on fixed wards to be erroneous in principle, and defective in security. *Secondly*,—A specification of a new and infallible principle, which, possessing all the properties essential to security, will be a certain protection (as far as a lock is concerned) against thieves of all descriptions By Joseph Bramah, Engineer." Second Edition, London, 1815.

case, the bolt could be moved backwards and forwards. Now, this elevation of the slides may be accomplished by means of a tally T, which on being pressed against

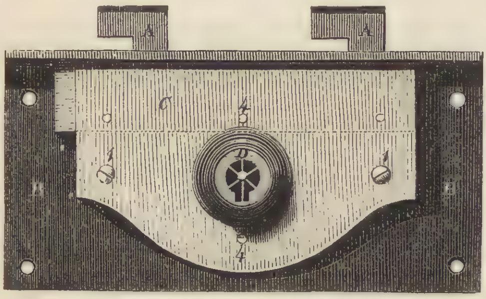


Fig. 1365. BRAMAH'S LOCK.

the lower extremities of the slides, will raise them all unequally, but nevertheless, so as to bring their notches into one horizontal line, and thus allow the bolt to pass. Supposing that only the lower ends of the slides are exposed to view, it is evident that in the absence of such a key or tally, it would be difficult, if not impossible, to ascertain how far to press in the sliders, so as to allow the bolt to pass. This simple illustration will assist the reader in understanding the details of the lock itself.

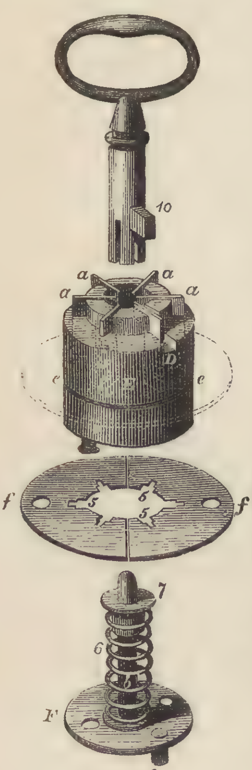


Fig. 1366.

Fig. 1365 shows the outside of one of Bramah's locks as adapted to a desk or box. Figs. 1366, 1367, 1368, 1369 give the details. A A, Fig. 1365 shows the bolt. It is formed like two hooks rising out of a bar of metal, which slides backwards and forwards upon the surface of the plate B B, the edge of which is turned up at right angles, and has openings through it for the hooked parts of the bolt to move in. The bolt is guided in its motion endways by sliding through square holes in the edge pieces of the lock, which are riveted to the main plate. A plate of metal C, is secured to the edge pieces by two screws 1, 1, and two steady pins. This plate prevents the bolt from rising up out of its place, and has a cylindrical projection D on its surface, which contains all the mechanism of the lock, and protects it from external injury. The projection D is neatly finished, and when the lock is put on a desk or box, its end projects through the wood a small distance, forming a very neat escutcheon, having the key-hole in its centre. Fig. 1366 shows a perspective view of the mechanism of the lock withdrawn from its case D. It consists of a barrel or cylinder E pierced with a cylindrical hole through its centre. The inside of the hole has 6 narrow grooves cut through its length, and in the direction of radii, from the centre towards the outside by the cylinder E, but leaving a sufficient strength all round. These grooves are fitted with small sliders of the form shown at *a a*, Fig. 1367, being split in thickness, and forced into the grooves, so as to move up and down therein with a slight friction, that they may not fall down by their own weight. They have small notches 2, 3, 3, cut in the back part, the use of which will be hereafter explained. The lower part of the opening through the cylinder E, is closed by a circular plate of metal F, Fig. 1366, fixed by two screws. It has a pin *b*, projecting up from its surface, which forms the centre for the pipe of the key to slide over. There is also another short circular stud *c*, on its under side, which enters into the curved opening *d*, in a part of the bolt at Fig. 1368. The stud *c* revolves with its plate F, and the cylinder E; and by the form of the opening *d*, moves the bolt backwards and forwards. It now remains to show how the cylinder E is prevented from being turned round, so as to move the bolt without the proper key being introduced. The cylinder has a circular groove or notch cut round its circumference at *e e*, to such a depth as to intersect the straight radii or grooves some distance, but still leaving a ring of metal round the hole through E, or it would fall into a number of pieces. Into the notch *e e* a thin circular plate of metal, in the form of *f f*, Fig. 1366, is introduced, having a hole through its centre, the same size as the bottom of the notch. It is divided into two halves to enable it to go round the cylinder, as seen at *f f*, Fig. 1369, and dotted in Fig. 1366, and when the mechanism of the lock is introduced into the case D, the plate *f f* is held fast, and secured by two screws, 4 4 (Figs. 1365 and 1369) to the plate C, in which situation the cylinder E with its appendages can be turned round by its key, but cannot move up or down, the plate *f f* preventing it. We shall now

Fig. 1367.

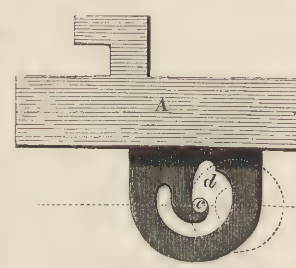


Fig. 1368.

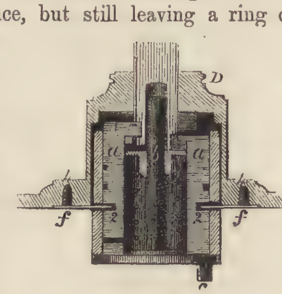


Fig. 1369.

proceed to explain how the key operates to turn the cylinder E and move the bolt A A. The plate *f f*, Fig. 1366, has 6 notches, 5, 5, 5, &c., filed round the inside. Through these notches the sliders *a a* can move up and down when the plate is in its place; but cannot move round with the cylinder E in a circle, unless the sliders are all depressed in their grooves, so that the deep notches 2, Fig. 1369, of all the 6 sliders come into the plane of the circular plate *f f*, as shown by the section Fig. 1369, in which state the cylinder with its sliders may be turned round in order to shoot the bolt. Now if any one or more of the sliders are pressed too low, or are not long enough, to come into the plane of *f f*, the cylinder cannot be moved round, because they are intercepted by the edges of the notches 5, 5. In the plate *f f* the whole number of sliders is pressed up, or caused to rise in their grooves, as far as the top of the cylinder E, by a spiral spring 6, coiled loosely round the pin *b*, Fig. 1366. This forces up a small collet, 7, on which the steps 8 of the sliders *a a*, Fig. 1367, rest. The first locks were made with a separate and independent spring to each slider, but it is a very great improvement, the introduction of one common spring to raise up the whole number; because if a person attempts to pick the lock by depressing the sliders separately by means of any small pointed instruments, and by chance brings two or more of them to the proper depth for turning round, should he press any one too low he has no means of raising it again without relieving the spring 6, which immediately throws the whole number of sliders up to the top, and destroys all that had been done towards picking the lock. Another improvement of this lock, and one which very much increased the difficulty of picking, and its consequent security, was the introduction of two false and deceptive notches cut in the sliders as seen at 3, 3, Fig. 1367. It was found that in the attempt to pick this lock, an instrument was introduced by the key-hole to force the cylinder E round. At the same time that the sliders were depressed by separate instruments, those sliders which were not at the proper level for moving round were held fast by the notches 5, 5, in the plate *f f* bearing against their sides, but when pressed down to the proper level, or till the notch 2 came opposite *f f*, they were not held fast, but were relieved. This furnished the depredator with the means of ascertaining which sliders were pressed low enough, or to the point for unlocking. The two notches 3, 3, in the sliders are sometimes cut above the true notch 2, sometimes below, and at other times on each side, and are not of sufficient depth to allow the cylinder E to turn round, but only to mislead any one who attempts to pick, by his not knowing whether it is the true lock or otherwise, or even whether the slider be higher or lower than the true notch.

Another recommendation of Bramah's lock, is the smallness of the key, which can be carried about the person of the owner without inconvenience. The form of the key is shown at 10, Fig. 1366. It has 6 notches cut round its edge of different depths, to press the slider down each a proper quantity. It has also a small projection from its side, which enters the notch D (Fig. 1366), in the cylinder E to turn it round, and throw the bolt. The bolt of this lock is prevented from being forced back when locked by the stud *c* on the bottom F of the cylinder, Fig. 1366, coming into a direct line with its centre of motion, as shown at *c*, Fig. 1368, when no force, however great, applied to drive the bolt back, would have any tendency to turn the cylinder E round. This prevents the mechanism from being injured, though it is very delicate. These locks are sometimes made with eight or more sliders.

The patents which have been taken out at various times for real or pretended improvements in locks, are very numerous. Mr. Chubb has collected a list of English patents granted between the years 1774 and 1849, and they amount to 84 in number. It would be useless to give an analysis of these patents, since, with the exception of Bramah's, Barron's, Chubb's, and a few others, they mostly consist of variations in the form and arrangement of the tumblers, slides, &c., and in very many cases without any apparent reason. It will be useful, however, by way of recapitulation, to refer to the collection of locks now in the possession of Mr. Hobbs, exhibited by Mr. C. Aubin of Wolverhampton. It attracted little or no attention during the Exhibition, and it is not even alluded to in the Jury Reports, and yet this collection may fairly be pronounced as of first-rate value, of great historical interest, and showing in the arrangement considerable mechanical skill. It is entered in the Illustrated Catalogue thus :—" Specimens to illustrate the rise and progress of the art of making locks, containing 44 different movements, by the most celebrated inventors in the lock trade." The specimens are arranged round a central axis, upon a series of circular disks like a dumb-waiter, and the axis is terminated at the top with a Bramah lock and key. The whole series is so connected, that on turning the key at the top, the bolts of all the locks are shot or unshot at pleasure. We do not approve of the order in which they are arranged, but we will nevertheless adopt it.

No. 1 is called a *Roman lock.* It consists of a simple bolt with a binder spring, for holding the bolt in any position in which it is placed until a sufficient force is applied to overcome it. Thousands of locks are made on this principle, which has been already illustrated in Fig. 1360.

No. 2 is a *French lock:* it is the same as No. 1, with the simple addition of a friction roller.

No. 3 is marked *Ancient.* It is a bolt lock, and was found in an ancient building: it is an improvement on Nos. 1 and 2, as the bolt requires, before it can be shot, to be pressed down, in order to release it from a catch at the back end of the bolt.

No. 4, also marked *Ancient*, is a *single-acting tumbler* lock. By *single acting* is meant one that cannot be raised too high in order to release the bolt. Fig. 1361 will explain this. *Double-acting* tumblers, on the contrary, must be raised to the exact height to allow the stump to pass. See Fig. 1362.

No. 5. *An Ancient English lock*, with a *double-acting tumbler*, or one in which the tumbler, as just explained, must be raised to the exact height required, to allow the stump of the bolt to pass the *gating* or *gateway* of tne tumbler.

No. 6. *Modern English.* This is a single-acting tumbler.

No. 7. By *Mace.* Double-acting.

No. 8. *Summerford's first.* A double-acting *draw* tumbler; that is, a tumbler which draws down instead of being lifted as in most tumbler locks.

No. 9. *Indian.* Single-acting tumbler with pin.

No. 10. *Thompson,* 1805. The first lock with more than one tumbler. This lock has two tumblers, one single and the other double-acting.

No. 11. *Daniels.* Single-acting tumbler, differing only in form from those previously used:—a remark that will apply to a large number of subsequent patentees.

No. 12, *Walton.* No. 13, *Barron's* first patent, 1774. No. 14, *Bickerton.* No. 15, *Dutch.* No. 16, *Duce,* sen. No. 17, *Sanders,* 1839, a double-acting tumbler lock with four tumblers. No. 18, *Cornthwaite,* 1789. (No. 17, patented in 1839, is the same in form and action as No. 18, patented in 1789. This remark will apply with more or less force until we come to No. 40: we shall therefore only give the names and dates.) No. 19, Richards & Peers. No. 20, Summerford's second. No. 21, Rowntree, 1790. No. 22, Duce, jun. first 1823. No. 23, Parson's first, 1832. No. 24, Bickerton's. No. 25, Price, 1774. No. 26, Aubin, 1830. In this lock a revolving curtain is introduced for the purpose of closing the key-hole during the revolution of the key. This same invention has been claimed in a patent, enrolled during the present year, 1852. No. 27, Barron's second, 1774. No. 28, Bird's, 1790. No. 29, Duce, jun. second, 1842. No. 30, Ruxton's, 1818. No. 31, Chubb's simplified, 1834. No. 32, Marr. No. 33, Tann, 1843. No. 34, Hunter, 1833. No. 35, Parson's second, 1833. No. 36, Young, 1830. No. 37, Lawton, 1815. No. 38, Strutt, 1819. No. 39, Scott, 1815. No. 40, Chubb's first, 1818. This is the original detector lock; and we may here state that whatever merit belongs to the detector lock is due to Mr. Chubb, senior. No. 41, Parson's third, 1833. This is the first *changeable* lock patented in England. The elevation of the tumblers is regulated by an adjusting screw passing through the lock to the inside of the door. This screw changes the *positive*, but not the *relative* position of the tumblers; so that the same difference in the steps of the key must be retained, the change being made only in the length of the bit. The number of changes for each lock is consequently very limited; in a lock of ordinary construction from 15 to 20 distinct keys can be applied. No. 42, Pierce, 1840. This lock is constructed on a plan suggested by the Marquis of Worcester in his "Century of Inventions:"—He says, "A lock may be so constructed that if a stranger attempt to open it, it catches his hand as a trap catches the fox; though far from maiming him for life, yet marketh him so that if once suspected he might easily be detected." In this lock a steel barb or sharp arrow-head is concealed below the key-hole, and if any person in attempting to open the lock should overlift a tumbler, the barb would be thrown off by a spring into his hand. It is said that the patentee himself experienced the efficacy of this invention, by receiving the barb into his own hand. No. 43, Ruxton's, 1816. This lock is furnished with a tell-tale, so that if the tumbler be overlifted, by attempting to pick the lock, a pin or catch is thrown out from the lock, and would be seen on unlocking the lock with the right key. Its action is similar to Chubb's detector, patented two years later, but the latter is much more simple and effective in its operation. Patents for detectors since the date of Chubb's first, are numerous: they all differ in form, and may be said to be equally effective; but they are alike in principle, and cannot be said to add much if any thing to the security of the lock. No. 44, Bramah, 1784. No. 45, Russell. No. 46, Mordan. The last two are repetitions of Bramah.

Although the Bramah lock differs completely in form from the tumbler lock, its principle of action is precisely the same. In the tumbler lock, there are a series of spring latches or tumblers, each of which has to be raised to a certain position, to allow a pin or stump fixed to the bolt to pass. In the Bramah lock, there are a series of slides, each of which has to be pressed down to a certain position so as to pass the locking plate before the bolt can be moved.

The question, whether such locks can be picked, was discussed with great zeal and earnestness during the Great Exhibition, when Mr. Hobbs, an American mechanician, accepted the challenge which had stood so many years in Mr. Bramah's shop window. It will be sufficient for our present purpose, to give the Report of the Committee appointed to see fair play between the parties. It is dated, 2d September, 1851:—

"Whereas for many years past a padlock has been exhibited in the window of Messrs. Bramah's shop, in Piccadilly, to which was appended a label, with these words:—'The artist who can make an instrument that will pick or open this lock, will receive two hundred guineas the moment it is produced;' and Mr. Hobbs, of America, having obtained permission from the Messrs. Bramah to make a trial of his skill in opening the said lock, Messrs. Bramah and Mr. Hobbs severally agreed that Mr. George Rennie, F.R.S., London, and Professor Cowper, of King's College, London, and Dr. Black, of Kentucky, should be the arbitrators between the said parties; that the trial should be conducted according to the rules laid down by the arbitrators, and the award of two hundred guineas decided by them on undertaking that they should see fair play between the parties. On the 23d July, it was agreed that the lock should be enclosed in a block of wood, and screwed to a door, and the screws sealed, the key-hole and hasp only being accessible to Mr. Hobbs; and when he was not operating, the key-hole to be covered with a band of iron, and sealed by Mr. Hobbs; that no other person should have access to the key-hole. The key was also sealed up, and not to be used till Mr. Hobbs had finished his operations. If Mr. Hobbs succeeded in picking or opening the lock, the key was to be tried, and if it locked and unlocked the padlock, it should be considered a proof that Mr. Hobbs had not injured the lock, but picked and opened it, and was entitled to the two hundred guineas. On the same day, July 23, Messrs. Bramah gave notice to Mr. Hobbs that the lock was ready for his operations. On July 24, Mr. Hobbs commenced his operations; and on August 23, Mr. Hobbs exhibited the lock open to Dr. Black and

Professor Cowper, Mr. Rennie being out of town; Dr. Black and Professor Cowper then called in Mr. Edward Bramah, and Mr. Bazalgette, and showed them the lock open. They then withdrew, and Mr. Hobbs locked and unlocked the padlock in the presence of Dr. Black and Professor Cowper. Between July 24 and August 23, Mr. Hobbs' operations were for a time suspended, so that the number of days occupied by him were sixteen, and the number of hours spent by him in the room with the lock was fifty-one. On Friday, August 29, Mr. Hobbs again locked and unlocked the padlock in the presence of Mr. George Rennie, Professor Cowper, Dr. Black, Mr. Edward Bramah, Mr. Bazalgette, and Mr. Abrahart. On Saturday, August 30, the key was tried, and the padlock was locked and unlocked with the key by Professor Cowper, Mr. Rennie, and Mr. Gilbertson, thus proving that Mr. Hobbs had fairly opened the lock without injuring it. Mr. Hobbs then formally produced the instruments with which he had opened the lock. We are, therefore, unanimously of opinion, that Messrs. Bramah have given Mr. Hobbs a fair opportunity of trying his skill, and that Mr. Hobbs has fairly picked or opened the lock, and we award that Messrs. Bramah and Co. do now pay to Mr. Hobbs the two hundred guineas."

Messrs. Bramah complied with this decision, but they objected to it on the ground that their challenge required that *an instrument*, i. e. only *one* instrument, should be used in picking or opening their lock; whereas Mr. Hobbs used three instruments, viz. a fork for pressing down the disc, a bit of steel for turning the cylinder, and a small stiletto for adjusting the slides. Whatever merit there may be in this objection, it does not affect the question as to the violability of all locks constructed with slides or tumblers known and in common use in this country, up to the date of the Great Exhibition, when the United States Department of that grand institution may be said to have introduced a new era into the art of lock-making in this country. We are not, for obvious reasons, going to initiate the reader into the art of picking locks, and we are inclined to agree with the Report of the Jury, Class XXII., in doubting "whether the circumstance that a lock has been picked under conditions which ordinarily could scarcely ever, if at all, be obtained, can be assumed as a test of its insecurity." But, on the other hand, it is fair to add, that, after a long and careful investigation of the merits of a vast number of locks, we are strongly inclined to agree with the position assumed by Mr. Hobbs, "that wherever the parts of a lock, which come in contact with the key, are affected by any pressure applied to the bolt, that lock can be picked." The time in which this can be done will evidently depend on the skill and experience of the operator. To illustrate this principle would be to explain how to pick most of the locks in ordinary use, which it may be prudent not to do. That lock-makers have tacitly admitted the truth of this proposition, is evident from the introduction of false notches, wards, rings, and curtains, in and about the key-holes. If the above proposition be true, it is evident that, in constructing a lock which shall not be capable of being picked, an entirely different principle must be adopted. This has been done, and we now proceed to explain the construction of a cheap lock patented and manufactured by Mr. Hobbs, which we believe, in the present state of the art of lock-picking, cannot be picked.

This lock, in its general appearance, resembles the usual tumbler locks: it has the same form of key and the same moveable parts, the only addition being attached to the *tumbler stump*, which addition works under the bolt of the lock. Fig. 1370 represents the mechanism of this lock: *b b* is the bolt; *t t*, the tumblers, with the usual slots or gatings, through

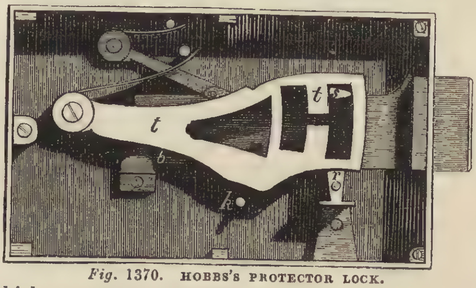


Fig. 1370. HOBBS'S PROTECTOR LOCK.

which a *tumbler stump*, *s*, must necessarily pass when the bolt is being locked or unlocked. In all other locks this *stump* is riveted into the bolt, consequently any pressure being applied, or an attempt made to withdraw the bolt, brings the *stump* against the face of the tumblers, causing them to bind, by which means the gatings are easily found. In this lock, on the contrary, the stump *s* is riveted into a piece shown detached in Fig. 1371; the hole *h*, fitting on a centre or pin in a recess, formed at the back of the bolt, and the stump, passing through a slot in the bolt, stands in its usual position; and there is a small binding spring to prevent the piece from turning of itself.

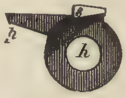


Fig. 1371.

When the key is applied to the lock, and the tumblers properly adjusted, the stump, meeting with no obstruction, passes through the gating of the tumbler; but should an attempt be made to withdraw the bolt before the tumblers are all properly raised, the stump, meeting with the slightest resistance, turns the piece to which it is attached on its centre, and raises the portion of the piece *p* so that it comes into contact with a stud riveted into the case of the lock, thereby preventing the possibility of withdrawing the bolt; at the same time releasing the tumblers from any pressure, so that it is impossible to ascertain their proper position. *d* is a dog, or lever, catching into the top of the bolt, serving as an additional security against its being forced back; *k* is the "drill-pin," on which the key, Fig. 1372, turns; *r* is a piece on which the tumblers rest. Although, by this simple addition, and without adding materially to the cost, locks are rendered perfectly secure against picking, or being opened by any instrument except the true key or its duplicates; yet, as with all other locks where the key is not susceptible of change, any person having had the key in his possession may, by taking an impression, become master of the lock. For purposes of absolute security this danger is effectually guarded against by the *permutating* or *changeable key* locks;

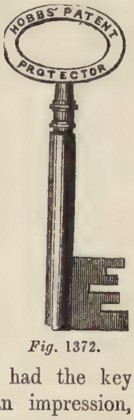


Fig. 1372.

a notice of which will lead us into some details respecting the progress of lock-making in the United States of America.

Twelve or thirteen years ago, the locksmiths of the United States of America did not doubt the security of the best locks, such as were in common use in England. They believed them to be proof against all known means of picking or of forming a false key, by any knowledge obtained by an inspection through the key-hole; yet it was thought desirable to secure them against the chance of the true key being copied, and thus an opening effected. Accordingly, Mr. Andrews, a mechanician of Perth Amboy, in the State of New Jersey, endeavoured to construct a lock so that the party using it could change its form at pleasure. His lock was similar to that of Chubb, having a series of tumblers and a detector; but before placing the lock on the door, the purchaser could arrange the tumblers in any way as the combination suited his convenience; the key being made with a series of moveable bits, which could be arranged in a corresponding combination with the tumblers. In order to make a change in the lock without taking it from the door, each tumbler was so constructed that in the act of locking it could be raised or drawn out with the bolt. A series of rings was furnished with the key, corresponding with the thickness of the moveable bits of the key; and any one, or as many more of the bits could be removed from the key, and rings substituted. These bits being removed, and the rings taking their place, the corresponding tumblers would not be raised by the turning of the key, and consequently would be drawn out with the bolt, becoming in fact a portion of the bolt itself. Therefore, when a bit was removed, and a ring substituted, so much of the security of the lock was lost as depended on the tumbler that was not raised; consequently, a lock having twelve tumblers being locked with a key with alternate bits and rings, would evidently become a six-tumbler lock; but should a tumbler that was drawn out with the bolt be raised in the attempt to pick or unlock it, or should any one of the acting tumblers be raised too high, the detector would be thrown, and prevent the withdrawing or unlocking of the bolt until re-adjusted. This lock was in great repute in the United States, and was adopted by the principal banking establishments, and other large firms. The success of this lock soon brought competitors into the field.

The most successful of these was Mr. Newell, of Broadway, New York, who invented the Permutating lock, composed of a series of first and secondary tumblers, the secondary series being operated upon by the first series. Through the secondary series was passed a screw, having a clamp overlapping the tumblers on the inside of the lock, each tumbler in the series having an elongated slot to allow the screw to pass through. On the back of the lock was a small round key-hole, in which the head of the screw rested, forming as it were a receptacle for a small secondary key; so that when the large key gave the necessary form to the tumblers, the small key was applied and operated on the clamp-screw, clamping and holding together the secondary series, and retaining them in relative heights or distances imparted to them by the large key; the door was then closed, and the bolt projected, and the first series of tumblers fell again to their original position. The objection to this lock is the necessity for a secondary key: also, that should the clamp-screw be left unreleased, the first series of tumblers would be held up by the secondary series, and an exact impression of the lengths of the several bits of the key could be obtained through the key-hole while the lock was unlocked.

To obviate the necessity for a secondary key, Mr. Newell made a series of notches on one of the secondary tumblers, corresponding in distance with the difference in the lengths of the several bits of the key. (See T^2 in Figs. 1, 2, of the steel engraving.) On turning the key each bit raises its plate or tumbler, so that some one of the notches presents itself in front of the tooth *t* on a dog or lever, L L. As the bolt is projected, the tooth being pressed into the several notches, the secondary series are held in their position by the tooth of this dog or lever, as shown in Fig. 2 of the steel engraving, instead of needing the secondary key. In unlocking the lock the tooth is again detached, the tumblers all fall into their original position, and the lock again becomes a blank, as in Fig. 1. These valuable additions to the detector and tumbler lock were made prior to the year 1841, but no improvement in the actual safety of the lock against picking had been hit upon. Mr. Newell found, in the course of his studies, that it was quite possible to pick both Andrews's lock and his own, and that with a very simple instrument. This discovery he candidly made known, confessing that his own lock, as well as all others based on the tumbler principle as then arranged, was insecure.

To contrive a really secure lock was, therefore, the aim of his further studies. First, a series of complicated wards were added to the lock; but these proving ineffectual, the notching of the abutting parts of the first and secondary series of tumblers, or of the stump face, and the ends of the tumblers, together with a revolving curtain closing the key-hole, were resorted to. Thus if a pressure were put upon the bolt, the tumblers could not be successively raised by the picking instrument in consequence of their being held fast by these false notches. This lock was considered effectual, and for some time baffled the skill of the country, until an engineer, named Pettis, accepted the challenge, and won the reward of five hundred dollars, offered by Messrs. Newell & Day to any one who should pick the lock. This lock was shown in the United States Department of the Great Exhibition, and was very remarkable for its beautiful workmanship.

These repeated trials had proved that security cannot be attained by adding difficulties, therefore Mr Newell endeavoured to construct a lock in such a manner that the obstruction to the withdrawing of

Fig. 1.

Elevation shewing the Bolt unlocked and the Auxiliary tumbler. Detector-Plate, and Cover removed.

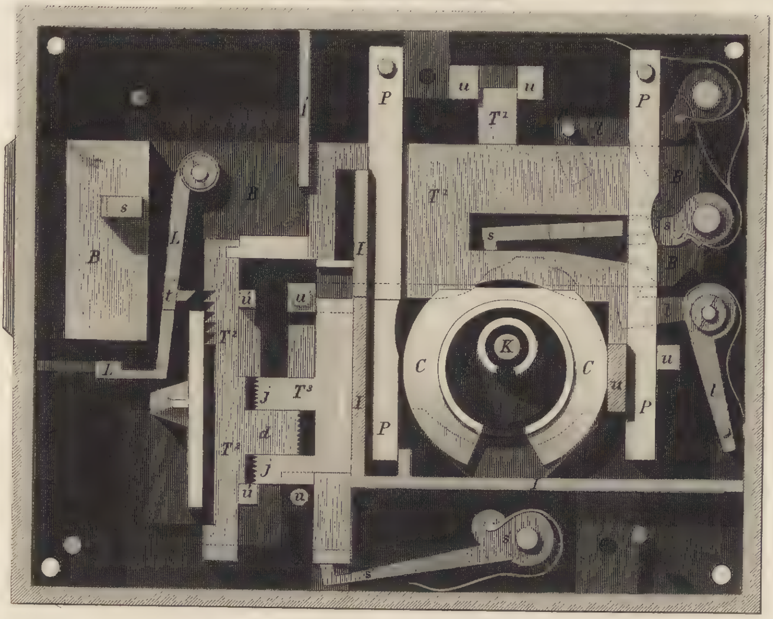


Fig. 5.

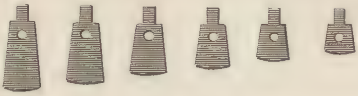


Fig. 4.

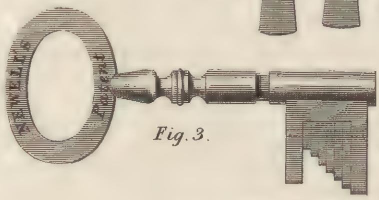


Fig. 3.

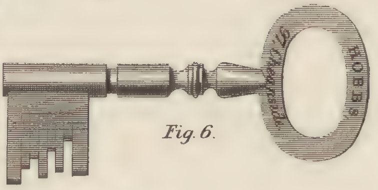
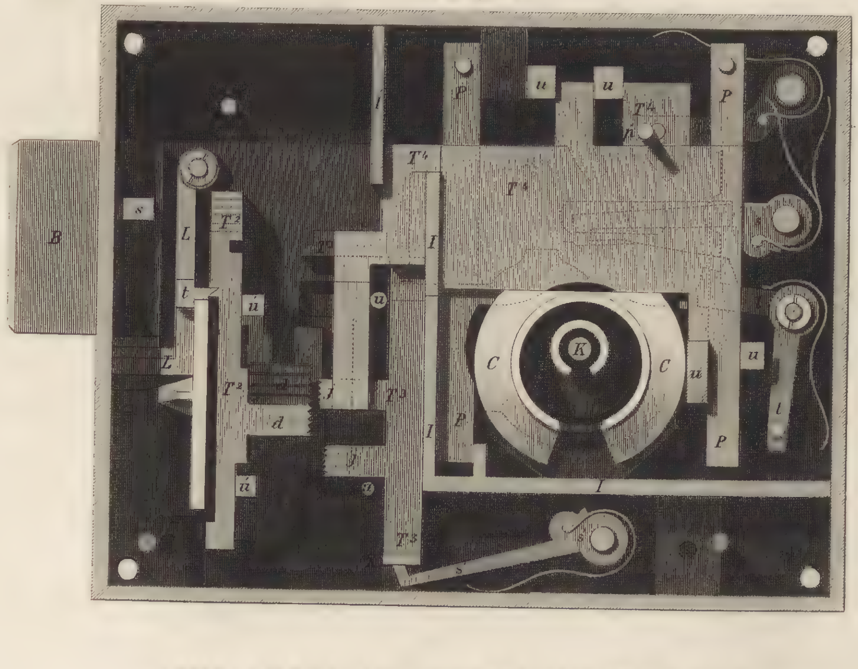


Fig. 6.

Fig. 2.

Bolt locked, Detector-Plate removed, and the Auxiliary tumbler in its place.



the bolt could not be ascertained through the key-hole. In his Parautoptic[1] lock he accordingly retained the good points of the former locks, and sought to guard against their defects. Fig. 1 of the steel engraving represents the lock unlocked, with the cover or top-plate removed, also the auxiliary-tumbler and the detector-plate are removed. Fig. 2 shows it locked, with the cover and the detector-plate removed and the auxiliary-tumbler in its place. Fig. 1373 is the lock with the cover on, showing the detector-plate. Fig. 3 of the steel engraving is the key; and Fig. 4 an end view of the key, showing the screw by which the separate bits are fixed in the key. Fig. 5 shows the six bits of the key detached; and Fig. 6 shows the same key as Fig. 3, but having the bits arranged in a different succession, thus forming a different key.

B B, in Figs. 1 and 2, is the bolt. T^1 are the first series of moveable slides or tumblers; *s*, the tumbler springs; T^2, the secondary series of tumblers; and T^3, the third, or intermediate series between the first and secondary series of tumblers. P P are the separating plates between the first series of tumblers, s' the springs for lifting the intermediate slides or tumblers, to make them follow the first series when they are lifted by the key. On each of the secondary tumblers, T^2, is a series of notches, corresponding in distance with the difference in the lengths of the movable bits of the key: as the key is turned in the lock to lock it, each bit raises its tumbler, so that some one of these notches presents itself in front of the tooth *t* on the dog or lever, L L. As the bolt B is projected, it carries with it the secondary tumblers T^2, and presses the tooth *t* into the notches, withdrawing the tongues *d* from between the jaws, *j j*, of the intermediate tumblers T^3, and allowing the first and intermediate tumblers to fall to their original position; while the secondary tumblers T^2 are held in the position given to them by the key, by means of the tooth *t* being pressed into the several notches, as shown in Fig. 2. Should an attempt be made to unlock the bolt with any but the true key, the tongues *d* will abut against the jaws, *j j*, preventing the bolt from being withdrawn; and should an attempt be made to ascertain which tumbler binds and requires to be moved, the secondary tumbler, T^2, that takes the pressure (answering the same purpose as the movable stump in the lock, Fig. 1370) being behind the iron wall, I I', which is fixed completely across the lock, prevents the possibility of its being reached through the key-hole, and the first tumblers, T, are quite detached at the time, thereby making it impossible to ascertain the position of the parts in the inner chamber behind the wall I I'. The portion I I of this wall is fixed to the back plate of the lock, and the portion I' to the cover. K is the drill-pin, on which the key fits; and C is a revolving ring, or curtain, which turns round with the key, and prevents the possibility of inspecting the interior of the lock through the key-hole: and should this ring be turned to bring the opening upwards, the detector-plate, D, (see Fig. 1373), is immediately carried over the key-hole by the motion of the pin p' upon the auxiliary tumbler T^4, which is lifted by the revolution of the ring C, thereby effectually closing the opening of the key-hole. As an additional protection the bolt is held from being unlocked by the stud *s* bearing against the

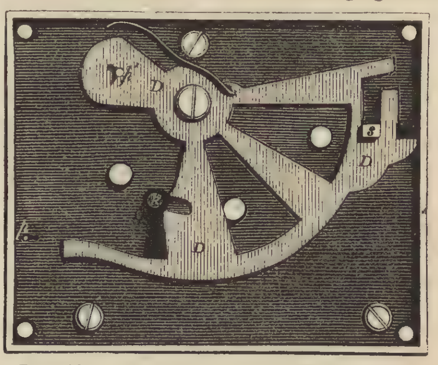


Fig. 1373. EXTERIOR OF THE PARAUTOPTIC LOCK.

plate D; also the lever *l l* holds the bolt when locked until it is released by the tail of the detector-plate *d'* pressing the pin *p*. *l'* is a lever, holding the bolt on the upper side, when locked, until it is lifted by the tumblers acting on the pin p'. X X are separating plates between the intermediate tumblers T^3; *u u* and *u' u'* are the studs for preserving the parallel motion of the different tumblers.

The most remarkable feature of this lock is, that it changes itself to the key, so that in whatever way the moveable bits on the key are arranged, the lock answers to that form without moving any part of it from the door. The purchaser of the lock can change the arrangement of the key at pleasure. By altering the numerical position of the bits in the key, the lock, in fact, alters itself to any number of new locks equal to the permutation of the number of bits on the key. If a 6-bit key, the lock can be changed 720 times; if 7 bits, 5,040 times; if 8 bits, 40,320 times; if 9 bits, 362,880 times; if 10 bits, 3,628,800 times; and if 12 bits, 479,001,600 times. Two extra bits are supplied with each key, which add very much to the number of changes. As the key turns round, each bit raises its tumbler to a point corresponding with its length, imparting to the first and second series the exact form of the key. The secondary series of tumblers being carried out with the bolt, and the tooth on the lever being pressed into the several notches on the front face of the secondary series, holds them in the position given them by the key, while the other portions of the lock fall again to their original position. In attempting to pick the lock, should a pressure be put on the bolt to ascertain the obstruction, it will be readily seen that it will be brought to bear on the third or intermediate tumblers. To prevent the possibility of reaching these, there is a wall of metal fixed across the lock, which confines the operator wholly to the key chamber. By detaching the portion of the tumbler that takes the pressure given to the bolt from the parts that can be reached through the key-hole, leaving that portion always at liberty

(1) That is, *covered from sight*.

the possibility of ascertaining what is wrong is cut off, thereby throwing the whole security of the lock into a chamber beyond the wall of metal, which is wholly inaccessible, and forming, as it were, another lock without a key-hole.

There is another source of insecurity that has still to be provided against: when the tumblers can be seen through the key-hole, if the underside of them be previously prepared, so that the key may leave a distinct mark the next time it is used, showing where it began to touch each tumbler in lifting it, the exact length of each bit of the key can be measured, and a correct copy of the key be made. The possibility of seeing the tumblers is here prevented by surrounding the inside of the key-hole with the ring or revolving curtain, and when this curtain is turned, to bring the opening opposite the tumblers, the key-hole is shut on the outside by the detector-tumbler. Should the lock be charged with gunpowder through the key-hole, for the purpose of blowing it from the door, the plug in the back of the key-chamber would yield to the force, leaving the lock uninjured, the curtain protecting the interior.

LODE. See Loadstone—Mining.

LOGWOOD. An important tree for dyeing purposes, first discovered in the bays of Campeachy and Honduras, growing in the greatest luxuriance. It is a member of the sub-order *Cæsalpineæ*, which includes *Brazil-wood* or *Pernambuco-wood*, *Cam-wood*, and other dyes, with several esteemed fruits, as *tamarinds*, the seeds of the *Carob* or *Locust-tree*, &c.; also purgative medicines, as *senna*, the whole being comprised in the vast order of *leguminous*, or *pod-bearing* plants.

Logwood, or as it was once called, *block-wood* (*Hæmatoxylum campechianum*), was first introduced into England in the reign of Queen Elizabeth. It was found to yield a violet-coloured dye, and with other ingredients, a black dye; but it was soon prohibited by act of parliament, as affording a "false and deceitful" colour, alike injurious to the queen's subjects at home, and "discreditable beyond seas to our merchants and dyers." This prohibition was strictly adhered to, so that wherever this valuable dye was found, it was seized and burnt. The prejudice against it as yielding a fugitive colour, arose from the unskilfulness of our dyers, and their ignorance of the proper mordants. When this ignorance was removed, the act which prevented the use of this dye was repealed: this occurred in 1661, when it was stated that "the ingenious industry of these times hath taught the dyers of England the art of fixing colours made of logwood, so that by experience they are found as lasting and serviceable as the colour made with any other sort of dye-wood."

The demand for logwood, after this period, greatly increased; but the supply was obtainable only in the Spanish possessions in America. The English, however, from the north Continent of America, tempted by the hopes of establishing a profitable trade, ventured to cut down logwood-trees in the unfrequented portion of the province of Yucatan, and finding that the Spaniards took no notice of their proceedings, they soon formed a small settlement at Laguna de Terminos, within the colony, with the full knowledge that they were intruders on the soil of other colonists. The English settlement flourished greatly, and large quantities of wood were shipped for New England and Jamaica. This went on for several years, and still without exciting the jealousy of the Spaniards, until the supply of logwood failing at the original spot, the settlers proceeded further into the country, and commenced building houses, and establishing themselves in a new district. The Spanish colonists then suddenly arose, and seized on two English ships laden with logwood, in revenge for which, the English took possession of a Spanish bark. A series of hostilities then took place, which ended in the forcible ejection of the English intruders from Laguna and the neighbourhood. This act of justice was not long maintained: the triumph of the Spaniards was transitory, and in two or three months the persevering English settlers had contrived to regain what they had lost, and were cutting logwood more diligently than ever in the old quarter. The wild and unrestrained life of the log-wood cutter has charms of its own, which were sufficient to detain the adventurous Dampier for ten or twelve months in Campeachy, and to engage his pen in interesting descriptions. "The logwood cutters," he says, "inhabit the creeks of the east and west lagunes in small companies, building their huts by the creek's sides, for the benefit of the sea-breezes, as near the logwood groves as they can. * * * Though they build their huts but slightly, yet they take care to thatch them very well with palm or palmet leaves, to prevent the rains, which are there very violent, from soaking in. For their bedding they raise a barbecue, or wooden frame, three feet and a half above ground, on one side of the house, and stick up four stakes, at each corner one, to fasten their curtains; out of which there is no sleeping for moskitoes. Another frame they raise, covered with earth, for a hearth to dress their victuals; and a third to sit at when they eat it. During the wet season, the land, where the logwood grows, is so overflowed that they step from their beds into the water, perhaps, two feet deep, and continue standing in the wet all day, till they go to bed again: but, nevertheless, account it the best season for doing a good day's labour in.

"Some fell the trees, others saw and cut them into convenient logs, and one chips off the sap, and he is commonly the principal man; and when a tree is so thick that after it is logged it remains still too great a burden for one man, we blow it up with gunpowder. The logwood cutters are generally strong sturdy fellows, and will carry burthens of three or four hundredweight."

The logwood settlements continued to be regarded with a hostile eye by the Spaniards, and this led to the attempt (which has proved eminently successful) to introduce the tree into our West India islands. Subsequently, however, the matter formed the subject of a treaty between the governments of England and Spain; and the subjects of Great Britain became pos-

sessed of a legal title to cut and ship logwood in the bay of Campeachy.

The logwood-tree was introduced into Jamaica in 1715. Seeds were procured from Campeachy, and produced plants which in three years were ten feet high. Plantations were then formed, and in a comparatively short time the tree was to be found all over the island, flourishing luxuriantly, either in plantations or as single trees, or in dense hedges, resembling our hawthorn. The full height of the tree is from 16 to 24 feet, and the trunk is sometimes 5 or 6 feet in circumference. The stems are crooked, the branches irregular and armed with thorns, the leaves bright and winged, the flowers in clusters, of a pale yellow colour, with a mixture of purple. The wood is very hard and heavy, of a deep orange-red colour, the decoction deep violet or purple, changing to yellow, and then black. It is made yellow by acids, and deepened by alkalies. It can be made very durable by the judicious use of mordants. For a violet dye, alum and tartar are used; for blue, acetate of copper; for black, acetate of iron.

Fig. 1374. LOGWOOD CUTTING MACHINE.

The wood is imported in large blocks about three feet long. These are cut up into chips by means of the machine shown in Fig. 1374, which consists of a series of steel cutters, arranged on a drum, moving on a horizontal axis, and to which a rapid motion is imparted by steam power. The logs are placed in a bed-frame, and their ends are constantly urged up against the revolving drum by a powerful lever, which the man holds in his hand. The chips fall into a pit below the drum, and a cylindrical cover prevents them from being scattered, and also prevents accidents from the steel cutters.

Logwood is preferred when old, containing black wood and very little of the white alburnum. It is denser than water, compact, and almost indestructible. It is excellent for fuel, and according to Dampier, is advantageously used in the hardening and tempering of steel. When chipped and exposed to the air, it loses much of its dyeing power. In the dyehouse logwood is used for the production of certain reds and blues, but its chief consumption is for blacks, which are obtained of various intensities by means of iron and alum bases.

The characteristic principle of log-wood is called *hematine* or *hæmatoxyline*, and is best obtained by pulverising the watery extract of the wood as prepared for pharmaceutical use, mixing it with a portion of sand to prevent agglutination, and digesting the mixture with six or eight times its volume of ether; it should be frequently shaken, and after a few days the clear brown tincture poured off, and the greater part of the ether distilled from it; the residue is then mixed with water and left to spontaneous evaporation in a lightly covered basin. After some days, the hæmatoxyline crystallizes, and may be washed with cold water, and pressed between the folds of bibulous paper to free it from the mother liquor. The crystals are transparent, prismatic, of a brownish-yellow, and yield a pale yellow powder. As analysed by Erdmann, hæmatoxyline in its anhydrous state contains C_{40} H_{17} O_{15}. Its solution is rendered colourless by sulphuric acid. Potash and ammonia render it dark purple-red, or if added in large quantity, they change it from violet to reddish brown or yellow. Baryta water if added to a solution of hæmatoxyline in water deprived of air first produces a white or pale blue precipitate, but this presently becomes blue, then red and brown. Chloride of tin gives a rose-coloured precipitate; alum a red colour without precipitation. The most sensible test of hæmatoxyline is pure or carbonated ammonia, which, under the influence of the air, reddens the smallest trace of it.

LOOM. See WEAVING.

LUCIFERS. See MATCHES.

LUPULINE, the bitter aromatic principle of the hop. See BEER, vol. i. page 113.

LUTES, (from *lutum*, clay,) are soft adhesive mixtures, principally earthy, used either for *closing* apertures at the junction of different pieces of apparatus, or for *coating* the exterior of vessels which are to be subjected to a high temperature, in order to strengthen them and prevent their fracture, or for the purpose of repairing a fracture, or for preventing the contact of the air.

Lutes used for the purpose of making junctions in apparatus tight, are numerous in consequence of the variety of vapours which require to be confined, and the difference of temperature to which they are subjected. The principal lutes are:—1. *Stourbridge clay* in fine powder: it should be made into a paste with water, the consistency being regulated according to the purposes required. It sustains a higher heat than any other English lute. 2. *Windsor loam*, obtained at Hampstead, &c., is a natural mixture of clay and sand in such proportions as to make an excellent lute. These two lutes may be used for coating vessels, or for making tight the hot joints of metallic vessels. 3. *Willis's lute*, for making earthenware retorts impervious to air or vapours. 1 ounce of borax is dissolved in half a pint of boiling water, and as much slaked lime added as will make it into a thin paste. This is to be spread over the retort with a brush, and when dry, a coating is to be applied of

slaked lime and linseed oil, beaten together until it becomes plastic. In the course of a day or two this will be sufficiently dry for use. 4. Mixtures of pulverized borax with the clay lutes 1, 2, or with common clay, form fusible fluxes, useful for glazing over the surfaces of vessels so as to close their pores. The clay with about $\frac{1}{10}$th by weight of borax may be made into a paste with water, and laid on with a brush. 5. *Fat lute* is prepared by beating dried and finely pulverized clay, (pipe-clay or Cornish clay,) with drying linseed oil until a soft and ductile mixture is produced. It is used for the junctions of apparatus which are liable to considerable elevation of temperature, or to prevent the escape of corrosive vapours. The lute may be kept on by tying strips of bladder round it. 6. *Parker's cement* mixed with water gradually sets and becomes quite solid and hard. It may be rendered quite tight by being brushed over with a melted mixture of equal parts wax and oil. 7. *Plaster of Paris* mixed with water or a thin solution of glue, makes a hard strong lute, but it will not support a very high temperature. 8. *Caustic lime* mixed with certain mineral and vegetable substances in solution, affords numerous cements and lutes, which, when dry, are hard and impervious to vapours. A powerful cement may be formed with lime and white of egg diluted with its bulk of water. When the white of egg is thoroughly mixed with the water, the dry slaked lime in powder is to be added by sprinkling in enough to make a thin paste, which must be well and quickly mixed. The mixture is then put upon slips of cloth, and applied round the junction to be luted, and a little dry lime sprinkled over the exterior. The substance soon hardens and adheres strongly. Instead of white of egg a moderately strong solution of glue may be used; or the serum of blood; or a mixture made by rubbing down very poor cheese with water in a mortar until of the consistency of cream. 9. *Iron cement*, for making permanent joints generally between surfaces of iron. Clean iron borings or turnings are to be slightly pounded, so as to be broken but not pulverized: then sifted coarsely, mixed up with powdered sal ammoniac and sulphur, and enough water to moisten the whole slightly. It is then to be rammed or caulked into the joints, and the latter drawn together as tightly as possible. The proportions are 1 sulphur, 2 sal ammoniac, 80 iron; no more should be mixed than can be used at once. 10. *White lead* ground up with oil and spread on slips of cloth, is useful for making joints tight. The slips should be drawn tightly round the joint and then bound with twine. Tow may be used instead of cloth. 11. Moistened *bladder* is often useful for closing a joint. If used with white of egg its adhesion is increased. 12. *Paste and paper*. The paste should be well boiled and thick, and the paper bibulous. Paper that has been pasted and allowed to dry, if moistened on the pasted side is ready for use in a few moments. 13. Paper prepared with a mixture of wax and turpentine[1] is also useful for making joints tight. Glue with paper or cloth is also useful. 14. *Linseed-meal* or *almond-paste* well beaten up with water is a good lute for cold joints. It will not bear a temperature above 600°. It is firmer if made up with milk, lime-water, or weak glue. 15. *Caoutchouc.* The method of forming a joint with this substance is described under CAOUTCHOUC, Fig. 438: its introduction, coupled with the improved and simplified methods of conducting chemical inquiries, may be said to have introduced a new era into the art of luting. "In the time of Lavoisier, accurate joints were more essentially necessary than at present. The general directions then given were to fix the apparatus firmly, and to cement it tightly and stiffly by strong luting. In this way many complicated instruments were combined into one great apparatus, so rigid in all its parts as to render it almost impossible to retain every junction perfectly close. The number of these junctions has in later times been very much diminished, and the introduction of elastic caoutchouc connectors has almost entirely removed that rigidity which was so dangerous to the apparatus, and fatal to its soundness."[2] 16. *Yellow wax* may be used as a lute; if melted with one-eighth its weight of common turpentine it becomes less brittle though more fusible. It should be moulded into cylinders or sticks, and thus preserved for use. 17. *Soft cement* consists of yellow wax melted with its weight of turpentine, and a little Venetian red to give it colour. When cold, it has the hardness of soap, but by the warmth of the fingers, and a little pressure, it becomes pliant, and may be moulded into any form required. It must be used at common temperatures, and will bear a considerable amount of shaking without being disturbed, which the hard lutes will not do. By melting soft cement, and dipping a cork into it, it will secure the contents of a bottle remarkably well. By moulding soft cement between the fingers into an acute cone, the point will be found useful for taking up small particles, such as crystals or fragments of bodies, for ocular examination. It is also convenient for effecting the adjustment of any crystal or reflecting body placed upon it in the required position. 18. *Cap-cement* is used for making close joints at common temperatures. It is used for attaching caps to pneumatic apparatus, gas jars, &c. It is formed of 5 parts by weight of resin, 1 part of yellow bees'-wax, and 1 part of red ochre, or Venetian red, in fine powder. The earthy substances must be well dried at a temperature above 212°. The wax and resin are to be melted together, the powder stirred in by degrees, and the heat continued a little above 212°, until all frothing ceases, and the mixture becomes tranquil. It is then to be allowed to cool, the stirring being continued until it has become so thick that the earthy matters will not subside by standing. Rolled into sticks, it may be used when required by fusing one end of a stick in the flame of a spirit lamp.

(1) Paper with a coat of gum or paste on one side is very useful for supplying ready labels. With a mixture of 1 part wax and 4 parts Venice turpentine, a coating is formed which adheres by the warmth of the hand: labels thus prepared may be immediately written on, and do not peel off.

(2) Faraday, Chemical Manipulation

In the great chemical manufactories lutes are used much more roughly than in the laboratory. Common mortar is used for luting gas retorts [see GAS]: and in recently walking through the chemical works at St. Rollox, near Glasgow, the Editor was painfully reminded of the imperfection of the lutes. The doors of the chambers used for the manufacture of bleaching powder were luted with mortar, but there was a considerable escape of chlorine. The workmen, however, regarded it with indifference, and they even entered the chambers when full of chlorine for the purpose of raking up the layer of lime deposited on the floor of the chamber, and they had no other protection than a wet handkerchief tied over the mouth. In other parts of these vast works the atmosphere was charged with sulphurous acid and muriatic acid gases, which were very painful to the lungs of one not accustomed by daily exposure to these irrespirable gases.

LYCOPERDON, a genus of fungi, which emit, when burst, a quantity of dust like seeds or spores, whence the species are commonly called *puff-balls.* The *L. giganteum* is used for tinder. The powder of *L. clavatum* is highly inflammable; it is known on the continent under the name of *vegetable brimstone,* and is used in the manufacture of fire-works, and also in pharmacy to roll up pills, which, when coated with it, may be put into water without being moistened. A quantity of this powder projected from a powder-puff or bellows across a flame forms the lightning of the theatres. This powder is also called *lycopodium.*

MACARONI, a preparation of fine wheat-flour, made into a peculiar paste or dough, and then manufactured into pipes or tubes. Macaroni is of Italian invention, and was long known in commerce as *Italian* or *Genoese paste.* The great seats of the manufacture are Naples and Genoa, but the process is so simple that there seems no good reason why it should not be carried on in this country; indeed, it is stated that a manufactory of this article, and of vermicelli likewise, has existed in Spitalfields since 1730. There were samples of inferior macaronis of English manufacture in the Great Exhibition: those from France were almost equal to the best Italian. Samples from Tuscany excelled in flavour, texture, and manufacture. There was also a fine series from Prussia.

The wheat used in the preparation of these luxuries is ground into a coarse flour, called *gruau* or *semoule* by the French; and for this purpose a pair of light mill-stones are employed, placed at a greater distance than usual from each other. This frees the wheat from the husk, and partially grinds it into small white grains, which form the basis of the finest pastes, the flour-dust being first separated by the boulting-machine. The best and most plastic dough is made with soft pure water, in the proportion of 12 lbs. water to 50 lbs. semoule. The water should be hot, and the dough well worked, but as it is too stiff to be kneaded by hand, other means are resorted to. According to one method, a wooden pole, about 14 feet long, is fastened at one end by a chain to a strong post fixed in the ground, so as to be moveable up and down like a lever, the paste being placed under one end. Two men take hold of the other end of this pole, and by elevating and depressing it alternately, and moving a little from side to side, they work the paste very thoroughly, the power of the lever being very great when acting in this manner. By another, and less agreeable method, the rough dough is piled one piece upon another, and trodden by the feet of the Italians for two or three minutes, after which it is worked for two hours with a powerful rolling-pin, or bar of wood from 10 to 12 feet long, larger at one end than at the other, and having a sharp cutting edge at the extremity attached to the kneading trough.

When by one or other of these processes the dough has been rendered perfectly smooth, it is next to be reduced to thin ribands, cylinders, or tubes, according as it is to be converted into vermicelli or macaroni. For the latter, however, a somewhat less compact dough is required than for the former. In either case a hollow cylindrical vessel of cast-iron is required, having its bottom perforated with large or small holes, or slits, as may be needed. When the cylinder is filled with paste, a piece of wood or a plate of iron that exactly fits it is forced in by means of a powerful press, and the paste is thus driven through the perforated bottom of the cylinder, taking of course the shape of the perforations. Macaroni is sometimes forced through the holes in the form of pipes, but it is oftener in fillets which are formed into tubes by joining their edges together before they have time to become dry. The macaroni is partially baked during the manufacture by a fire placed beneath the cylinder, whence it is drawn away and hung on rods placed across a room. In a few days it is dry enough for use. Macaroni left in the fillet or riband shape is called *lazagnes.* For vermicelli the holes in the cylinder are smaller, and the dough is more tenacious. The paste is forced slowly through the holes, and when the threads have reached the length of a foot they are broken off and twisted into any desired shape on a piece of paper. Macaroni is generally brought to table dressed with Parmesan cheese; it is also used in common with vermicelli for thickening soups, for puddings, &c.

MACE. See NUTMEG.

MACERATION. See DECOCTION.

MACHINE, a term applied to a variety of contrivances which bear but little relation to each other. Thus we speak of a *bathing-machine,* a *copying-machine,* a *threshing-machine,* an *electrical-machine,* &c. They agree in being more complex and artificial than the utensils, tools, and instruments used in a primitive state of society. Thus a *bathing-machine* is more complicated than a *tub,* and a *threshing-machine* than a *flail.* The ancient Greeks and Romans applied the term machine (μηχανή, *machina*) to every tool by which hand labour of any kind was performed; and we still limit the word *tool* to an implement which when in use is held in the hand of the operator. In modern language, the word *machine* is applied to such tools or instruments as are used for some philosophical purpose (as an *electrical-machine,* a *centrifugal*

machine, *la machine pneumatique*, *i.e.* the *air-pump*, &c.), or of which the construction employs the simple mechanical powers in a conspicuous manner (as in the *threshing-machine*). A machine is nearly synonymous with *engine* [see ENGINE], which is quite a modern term, and appears to be limited to machines of considerable magnitude, involving much art and contrivance, such as a *steam-engine*, a *fire-engine*, a *boring-engine*, a *dividing-engine*, &c. Neither the term *machine* nor *engine* is properly applicable to any contrivance by means of which some piece of work is not executed, or materials *manufactured*, as it is termed. A *bathing-machine* is certainly an inaccurate expression.

A machine derives its advantage in overcoming resistance from the reaction by which it supports a certain portion of the weight which produces that resistance, and the motive power has only to counteract the remainder. In those simple machines, called the mechanical powers [see STATICS], such as the *lever*, the *wheel and axle* and the *pulley*, there is the *resistance*, the *moving-power*, and the *reaction* of the machine, and one of these is always found to be equal to the sum of the two others. In any one of these machines any portion of the resistance may be made to rest on the point of support, or the point of suspension. In the *inclined plane*, the *wedge* and the *screw*, the motive power, the resistance, and the reaction of the support are represented by the three sides of a triangle, and the ratio of the first to either of the others may be varied at pleasure.

The motive powers which are applied to any object through the intervention of machinery may consist of the muscular strength of men or animals; or the actions of weights, springs, wind, water, steam, gunpowder, &c.; and these powers are usually regarded as *pressures* exerted during an indefinitely short period of time. The point in any machine to which the moving power is applied is called the *impelled*, and that against which the resistance acts, the *working point*.

In the use of a machine a portion of the power, and often very much the larger portion, is expended in overcoming the inertia and friction of the materials of which it is composed, and that which remains is all that produces any useful effect or *work*. The loss of power from inertia is doubled when a reciprocating motion exists in the same machine; because a momentary state of rest ensues between every two contrary directions of the movement, and immediately afterwards a new inertia is to be overcome. As the quantity of machinery is increased in an engine, the retarding forces are evidently augmented; so that it is important that every machine should be as simple as the relation between the power and the resistance will permit. So also in the construction of machinery all abrupt variations of velocity should be prevented, on account of the irregularity which they induce in the action of the machine. "It is also a maxim among engineers, that the impelled point of a machine should not be allowed to move with a greater velocity than that with which the motive power can act upon it; since in this case the excess of velocity in the machine will be employed in accelerating the motion of the power, and thus the general acceleration of the machine will suffer a corresponding diminution. The velocities of the impelled and working points should, therefore, be properly adjusted to the pressures, the inertia and the friction, in order that all possible advantage may be derived from the machine."

In estimating the power of a machine, it is impossible to take into account the effects of momentary accelerations or retardations of motion, and the loss from inertia and friction; hence the measure of the power is made to depend on the condition that the impelled and working points are in a state of uniform motion. In such a case, as in the property of the simple lever, the velocities of those extreme points are inversely proportional to the forces which would be in equilibrio at the same points; the rule is, "that in every machine, simple or complex, the pressure at the impelled point, multiplied by the velocity of that point, is equal to the product of the resistance at the working point by the velocity of the same point; or the momentum of resistance (called the *performance* of the machine) is equal to the momentum of impulse."

Professor Robison[1] has offered some well-considered objections to this rule, as it respects the measure of the power in action. A writer in the Penny Cyclopædia (article *Machine*) contends that it affords a correct value of the useful effect; and that this may be measured by the weight which might be raised by the machine to a given height vertically, in a given time. "The fact is sufficiently evident, when a mass of any material is to be conveyed from one place to another, or when a body is let fall on any object from a given height. It follows that if an algebraical expression be obtained for the momentum of the resistance in terms involving that resistance, the motive power and the distances of their points of application from the axis of motion; on making the differential of that expression equal to zero, the ratio of the resistance to the moving power, when the useful effect of the machine is a maximum, may be found from the resulting equation. If M represent the mass of a body moved, W its weight, which is equal to Mg, g ($= 32\frac{1}{6}$ feet) expressing the force of gravity; also, if H be the height to which the body may be raised in one second of time, and V the velocity which a body would acquire by falling vertically through a height equal to H, we shall have by the theory of motions, $V^2 = 2\,g\,H$; whence $W\,H$ (the momentum of resistance, or the useful effect of a machine) $= \frac{1}{2}\,M\,V^2$. This last expression is designated the *living*, or *active force* of the body moved; and it expresses the force of a body in motion, in contradistinction to the simple pressure exercised by a body at rest."

It is often stated that, in employing machinery, as much is lost in time as is gained in power, or that the momentum of resistance is proportional to the power employed. This rule is applicable when the object

(1) See an admirable article entitled *Machinery* in the second volume of the "System of Mechanical Philosophy."

moved resists by its inertia only; "but if the inertia is but a small part of the resistance, the momentum of the latter, or the work done, is found to increase nearly as the square of the power employed"

MACLE, a term applied to crystals of andalusite, which show a tesselated or cruciform structure when broken across and polished. This structure appears to be due to impurities from the gangue disseminated during crystallization in a regular manner along the sides, edges, and diagonals of the crystal.

MADDER, a well-known red dye, exceedingly valuable on account of the various shades of colour which can be obtained from it by means of the several mordants employed by the dyer, and also for the permanency of the colours thus produced. The madder plant, *Rubia tinctoria*, is a native of the Levant, and of Italy, the south of France, and Switzerland. It is cultivated successfully in Holland, Russia, and other countries, but does not succeed in England. It is a luxuriant trailing plant, sending forth numerous large square jointed stems, armed with prickles, and bearing six or eight spear-shaped leaves in a whorl at each joint, the whole terminating in a loose spike of yellow flowers. The stalks are annual, but the root, which is the valuable part of the plant, is perennial. It is composed of many long thick, succulent fibres, covered with a black bark or rind; when this is removed they appear of a reddish colour and semi-transparent, with a yellowish pith in the centre. The taste is bitter, and the smell strong and peculiar.

The plant is propagated by shoots, which are planted in August, a foot apart, and allowed to remain two seasons, with attention to weeding. In the second year the plants blossom, and come to perfection: after their leaves have fallen off the roots are taken up, and carefully dried and cleaned for the market. When the roots are sufficiently dried outwardly by the action of the air and of kilns, they are then thrashed like corn for the purpose of removing the outer skin. This gives an inferior madder, called *mull*, which is packed away separately, and sold at an inferior price. The naked roots are now carried back to the kiln and subjected to a higher degree of heat than before, a current of air being introduced into the kiln, to carry off the exhalations from the plant, which would injure its colour. In very warm climates the roots are dried without artificial heat. After this they are ground into a coarse powder, which is of a dingy red or orange colour, and very apt to be deteriorated by moisture. The grinding is performed between mill-stones or under knives similar to those of a tan-bark mill. The powder is milled and bolted to different degrees of purity. In some cases the fresh root is more valued as a dye than the prepared madder; but its bulk becomes troublesome, and it cannot be preserved for any considerable period without deterioration. Nevertheless, madder, in the root, is largely exported from the seats of this trade. It is a singular circumstance respecting madder, that the bones of animals become tinged with the colour, when the roots are given them as food. In a growing animal, alternate layers of white and red bone may be obtained by the alternate use and disuse of this food.[1]

Madder affords an adjective dye, but this becomes permanent when the cloth to be dyed is previously prepared by boiling in a solution of alum and tartar. The colour is less brilliant than that from cochineal, but it is much less expensive, and is therefore the ordinary red dye for stuffs and cottons, but not for silks. It is peculiarly convenient in calico-printing, for by the use of different mordants every variety of tint may be obtained from pink to deep red, and from lilac to black. With a portion of weld or quercitron added to it, all the shades of brown and orange may be also produced. Tin, iron, and aluminous bases, as well as other mordants, are used for this purpose.

Madder has been carefully examined by eminent chemists, but the nature of its colouring principle is as yet but little understood. It has been doubted by some inquirers whether the variety of shades produced are due to the combination of madder with the different mordants, or whether several colouring matters are not contained in the substance itself, and severally precipitated or retained by the varying action of different agents. Two distinct colouring matters at least are clearly perceptible in madder, a fawn and a red, and the admixture of the former tends to diminish the brilliancy of the latter. In the far-famed *Turkey-red*, the red colouring matter alone is preserved therefore, this colour is not only more brilliant, but more durable than the other reds obtained from madder.

Madder-purple is obtained by washing the roots, and then repeatedly boiling them in a strong solution of alum, and filtering while hot. A brownish red substance falls, which is chiefly madder red: this is

(1) In a paper contributed by the Editor to the *Penny Magazine*, No. 856, this curious subject is treated at some length. The following are the chief points in the investigation:—About the year 1736, Mr. Belchier, surgeon, of London, dining at the house of a calico-printer, noticed that the bones of a joint of pork were of a red colour, when he was informed that the hogs kept at the establishment had usually mixed with their food the bran which had been boiled with printed calicos in order to brighten the madder dye. Belchier tried a few experiments on this subject, and recorded the result in the *Philosophical Transactions* for 1736. In 1739 Duhamel repeated the experiments on chickens, pigeons, and sucking-pigs. The bones were coloured red, and on withholding the madder they appeared to regain their usual colour; but, it was found that the red was merely concealed by a deposit of white bone. Haller, Hunter, and others were interested in the subject, and they found that no point of ossification, however delicate or isolated from the rest of the osseous system, escaped the colouring action of the madder. In 1839 Flourens took up the subject: he found the action often to take effect in a few hours. It was noticed that in the eyes of pigeons fed on madder, a red circle was seen round the iris, the only portion of the eye that was so coloured. It was found that in birds there exists between the two plates of that portion of the eye anterior to the cornea, a circle of minute osseous pieces, which is absent in mammalia. By feeding a number of young pigs of the same age alternately upon food mixed with madder, and free from madder, he arrived at the conclusion that, in the growth of the bones, while fresh deposits are being made upon the exterior surface of the bone, absorption goes on within; so that as the whole diameter of the bone becomes increased, the internal canal is enlarged. The growth of the teeth is even more remarkable, for it is stated, that while the addition of fresh dental matter (*dentine*) is made on the interior, there is absorption on the external face. The enamel of teeth, cartilage, feathers, nails, claws, &c., are not coloured by madder.

separated, and sulphuric acid added to the clear liquor, which then throws down, by degrees, madder-purple: this is collected, boiled with hydrochloric acid, to separate alumina, and lastly digested in alcohol: from this tincture the greater part of the alcohol is distilled, and the residue, on spontaneous evaporation, deposits the so-called *purple* as a crystalline powder. This furnishes a rose-coloured solution in water, a deep red or purple solution in alcohol or ether. Acids render it yellow, alkalis deep red; chalk, boiled with the solutions, removes the whole of the colouring matter. *Madder-red*, which forms the principal part of the precipitate just alluded to, is separated by boiling in dilute hydrochloric acid, and then dissolving in alcohol. This solution, with alum, is heated to boiling, when the madder-red is thrown down in a purer form. It is further purified by dissolving in ether, when, on evaporation, it remains a yellow-brown crystalline powder. This gives to boiling water a dark-yellow colour, to alcohol and ether a reddish-yellow. With acids it is yellow, with ammonia purple, with caustic potassa violet. *Madder-orange* is obtained by digesting the washed roots for 16 hours in 8 parts water at 60°, and straining the infusion, which then deposits small crystals. These are dried and dissolved in boiling alcohol: the deposit which forms on cooling is madder-orange, which is to be washed with cold alcohol till the washings are no longer reddened by sulphuric acid. It then forms an orange-yellow powder, which when dissolved in boiling water forms on cooling yellow flocks. With caustic potassa its solution becomes rose-red, with ammonia reddish brown. The colouring matter is removed by chalk. There are also *madder-yellow* (*Xanthine*), and *madder-brown;* but the above, either singly or combined, give the various tints employed by calico-printers.

The terms *alizarine*, *purpurine*, and *garancine*, have been applied to madder-red and madder-purple, or to their sublimed products. Alizarine has been represented by the formula $C_{37}\,H_{12}\,O_{10}$.

An important branch of industry has of late years sprung up in the south of France in the preparation of garancine for exportation instead of the root. For this purpose the roots are first moistened with dilute sulphuric acid, and then exposed in considerable masses to a boiling heat by means of steam, by which the colouring matter is altered and improved for certain dyeing processes, and the quantity of soluble matter considerably increased. Spent madder, instead of being thrown away, is now also used as a source of garancine. It is treated in the same manner as the fresh roots, and thus a considerable quantity of colouring matter is recovered. The garancine in either case produces a more scarletty red than the ground root: it also affords good chocolate and black without soiling the white ground; but it is not so well adapted for purples, lilacs, and pinks.

Many very beautiful and durable dyes of red and purple are obtained under the name of *Adrianople* or *Turkey-reds.* The processes for these are very tedious and complicated, and the reasons for their adoption not well understood. Oil, sheep's dung, calf's blood, gall-nuts, soda, alum, and afterwards a solution of tin, have all been considered necessary to produce the rich tints in question; but some of these are dispensed with by our most eminent calico-dyers. A description of the German method, as practised at Elberfeld, will give an idea of the nature of the operations. One hundred pounds' weight of cotton is first cleansed by boiling 4 hours in a weak alkaline bath. It is then cooled and rinsed preparatory to immersion in a steep made of 300 lbs. of water, 15 lbs. potash, 1 pailful of sheep's dung, $12\frac{1}{2}$ lbs. olive oil. In this it is worked about, and then left for a night, after which it is drained, wrung out, and dried. The steeping and drying are repeated 3 times. It is next placed in a bath containing 120 quarts of water, 18 lbs. potash, and 6 qrts. olive oil, then wrung out and dried. This treatment is repeated 4 times. After this the cotton is steeped in the river for a night, slightly rinsed, and hung up without wringing to dry in the air. A warm bath of sumach and nut-galls is then prepared, and in this the cotton remains during a night, being strongly wrung afterwards and dried in the air. Alum, potash, and chalk are next employed, the cotton wrung, and worked well through the bath, in which it is left for the night. Draining and strong rinsings follow, which are repeated, with steeping in water to remove any excess of alum from the fibres.

After all these preparatory processes the cotton is ready for maddering. Blood, sumach, and nut-galls are added to the madder: the bath is brought to the boil in an hour and three-quarters, and is kept boiling half an hour. The cotton is then rinsed, dried, and boiled from 24 to 36 hours in a covered copper, with an oily alkaline liquid: then rinsed twice, laid for two days in clear water and dried. The last process, and that which gives the greatest brightness, is the boiling the cotton for three or four hours in a soap bath containing muriate of tin. Further steeping in water, rinsing, and drying, close this long series of operations.

The Glasgow methods differ in some respects from the above, but are productive of a beautiful and well-known Turkey-red. Unbleached calico is subjected to a fermentative steep for 24 hours, and washed at the dash-wheel. It is then boiled in a lye of 1 lb. soda crystals to 12 lbs. cloth. After this comes oiling: a bath is prepared consisting of Gallipoli oil, sheep's dung, solution of soda crystals, and of pearl-ash, with water making a milk-white soapy solution. This is put into a cylindrical vat, and agitated with wooden vanes; after which, it is let off, as it is wanted, into the trough of a padding machine, in order to imbue every fibre of the cloth in its passage. The padded cloth is often laid aside in wooden troughs for more than a fortnight, when it is again padded with the soapy liquor and spread out to dry. This is sometimes repeated a third and a fourth time, until the cloth is quite varnished with oil. It is then cleansed to a certain degree by being passed through a weak solution of pearl-ash, at the temperature of about

122° Fah., after which it is squeezed between rollers and dried. But this does not complete the oiling process. A second system now commences, the liquor being similar to the first, but without any admixture of sheep's dung. In this the cloth is padded as before, and passed through the squeezing rollers, which return the superfluous liquor to the padding-trough. The cloth is then laid on the grass, and finally hard dried in a stove. These processes are often repeated three times, and the cloth becomes so oleaginous as to require cleansing again in lye of soda crystals and pearl-ash. In recapitulating these operations, it appears very much as if the whole were a system of doing and undoing, and it cannot but occur to the scientific chemist, that a large field of inquiry is opened as to the nature and treatment of this valuable dye. It is affirmed that in the cleansing which follows upon the oiling of the cloth, a considerable portion of the alkalies enters into combination with the oil in the interior of the cotton filament.

The *galling* of the cloth is a very important step in the preparation of Turkey-red. About 20 lbs. of Aleppo galls, bruised and boiled for 3 or 4 hours in 25 gals. of water, is the proportion for 100 lbs. of cloth, but to make it successful all the oil must have been thoroughly saponified by the previous processes. The cloth is well padded in the decoction of galls, (sumach is sometimes substituted in the proportion of 2 lbs. for every 1 lb. of galls,) the temperature of the mixture being kept at 90°. Fah., then passed between squeezing-rollers, and dried. It is next transferred to a solution of alum, to which a certain portion of chalk is added, and in this mixture it is winced and steeped 12 hours.

Maddering is the next process, and for this 2 or 3 lbs. of madder, ground to powder, are taken to every pound of cloth. The cloth is put into the bath while cold, and winced by the automatic reel, until the liquor boils, and during two hours afterwards, in which the boiling continues. Bullocks' blood, in the proportion of 1 gallon for every 25 lbs. of cloth, is put into the bath while cold.

After the maddering comes a clearing process, to remove a dingy brown colouring matter which is associated with the fine red, and which is more fugitive. Every 100 lbs. of cloth are therefore boiled for 12 hours in water containing soap and soda, together with some of the residual matter from the last cleansing. This nearly removes the dun colour in question, but it is finally got rid of by a second boil at a heat of 250°, in a globular copper, with 5 lbs. of soap and 1 lb. muriate of tin crystals, dissolved in a sufficient body of water for 100 lbs. of cloth. This muriate of tin raises the cloth to a scarlet hue. When weather permits, the goods are laid out on the grass for a few days.

Many variations are introduced by different dyers, and so great is the importance attached to the process in France, that its particulars have been enumerated by government officers, and directions and recommendations given officially on the subject.

MAGAZINE, a strong building of brick or stone for containing gunpowder and other warlike stores. As gunpowder is liable to injury from damp, the situation must be selected so as to ensure dryness, and as uniform a temperature as possible. The magazine should be remote from other buildings, and furnished with metallic lightning conductors, and surrounded by a wall and ditch. In some cases, it may require to be made shell-proof. The dimensions vary with the quantity of powder to be stored. According to Vauban, magazines made in the ramparts of fortresses, should be from 8 to 12 feet wide, with semicircular headed vaults; the barrels of powder to be arranged in them in two rows, with a passage from 3 to 4 feet wide along the middle. The magazines constructed in this country on a large scale, consist of several parallel vaults, each about 90 feet long, and 19 feet wide, separated from each other by brick partition walls, communicating by doorways, and there is a doorway at the extremity of each vault. The side walls are from 8 to 10 feet thick, and are strengthened by buttresses. "The concave or interior surface of each vault in a vertical and transverse section, is nearly of a parabolical figure above the springing courses, and the exterior surface has the form of two inclined planes meeting in a longitudinal ridge line above the middle of the vault. The thickness of the brick-work forming the vaulted roof, is therefore various. At the crown it is 7 or 8 feet, and on the hances about 3 feet, this being considered sufficient to resist the shock of falling shells. The vault on the exterior of the inclined planes, is covered with flat tiles, and the gutter between every two roofs with sheet lead or copper. The height interiorly, from the level of the floor to the crown of the arch, is 19 feet; and the lines at which the vaulting springs from the side walls, are at half that distance above the floor. The narrow vertical perforations which are made through the side and end walls, for the purpose of giving air to the interior, are cut so as to leave a solid block or traverse of the brickwork in the middle of the thickness of the wall; the line of the perforation branching laterally from its general direction, and passing along the two sides of the traverse. By this construction, while air is admitted, no object capable of doing mischief can be thrown in from the exterior of the building. The flooring-planks are of course laid on joists raised considerably above the ground. One vault of the dimensions above given, would contain 2,500 barrels, or 225,000lbs. of powder."

MAGMA, a crude mixture of mineral or organic matters in a thin pasty state.

MAGNESIUM (Mg. 12), the metallic base of magnesia, was discovered by Davy in 1808, and its properties first made known by Bussy in 1830. It has the colour and lustre of silver, and is to a certain extent ductile. It changes much less slowly in the air than potassium and sodium, and does not decompose water at low temperatures. At 86°, water begins to be decomposed, and at 212° rapidly. Heated in the flame of a spirit-lamp, it burns with intense light into magnesia.

P 2

The only compound of magnesium and oxygen, is magnesia MgO. It is usually procured by exposing the carbonate to a red heat. Magnesia is a bulky white insipid powder, of sp. gr. of about 3. It has a slight alkaline reaction upon sensitive vegetable colours; but water which has been agitated with it, and then filtered, does not produce that effect. It is nearly insoluble in water. Cold water dissolves between $\frac{1}{5000}$th and $\frac{1}{7000}$th part; at 212° water dissolves $\frac{1}{36000}$th part. When exposed to air, it absorbs moisture and carbonic acid much less rapidly than the other alkaline earths; but by pouring water upon it, it is slowly converted into a *hydrate*, MgO,HO. The hydrate has been found native in Serpentine. Magnesia is almost infusible: a mixture of lime and magnesia is scarcely more fusible than the earths separately. Caustic magnesia is useful in cases of poisoning with arsenious acid, or common arsenic. It combines with this acid, and forms an insoluble compound. The hydrate, but not the carbonate, can be used for this purpose.

Magnesia forms saline compounds with the acids: they have a bitter taste. The sulphate is also distinguished from the sulphates of the other alkaline earths by its solubility. A few of the more remarkable salts of magnesia need only be distinguished here.

Sulphate of magnesia MgO,SO_3, is found in certain mineral springs, as those of Seidlitz, Leydschutz, Egra, and formerly Epsom, in Surrey, whence the name of *Epsom salts.* It appears in these cases to proceed from the reaction of the sulphate of lime held in solution in the water upon the magnesian limestone of the soil. Water charged with sulphate of lime, remaining for a considerable time in contact with the magnesian rock, reacts upon the carbonate of magnesia, and carbonate of lime is deposited, while sulphate of magnesia is dissolved. The latter salt may be obtained in a crystalline form by evaporation. This method of forming sulphate of magnesia may be illustrated by filtering slowly, and many times in succession, water saturated with sulphate of lime through a thick layer of magnesian limestone: the water will soon be found to contain sulphate of magnesia only. The reverse of this experiment is instructive. If carbonate of lime and a solution of sulphate of magnesia be heated to about 400° or 430° in a thick glass tube sealed at both ends, the result will be the formation of sulphate of lime and carbonate of magnesia. In this way, the natural magnesian limestones are formed by the reaction of carbonate of lime upon sulphate of magnesia dissolved in the thermal waters of the earth.

Sulphate of magnesia is also obtained by the action of sulphuric acid upon calcareous rocks rich in carbonate of magnesia, such as *dolomite.* The rock is calcined, and reduced to powder by being sprinkled with water; it is then diffused through water, and sulphuric acid is added: sulphate of lime and sulphate of magnesia are formed, the one scarcely soluble in water, and the other very much so; hence they are easily separated.

Epsom salts are also manufactured largely from the *bittern,* or mother liquor left after the evaporation of sea-water, and the separation of common salt therefrom. [See SALT.] This bittern consists chiefly of a solution of chloride of magnesium, and sulphate of magnesia. The process formerly adopted at Lymington, in Hampshire, was as follows:—During the summer, when the manufacture of salt was carried on, the bittern was collected in underground pits until the winter season, which afforded leisure for the conversion of this waste product. The bitter liquor from the pits was boiled for some hours in the pans which were used in summer in the preparation of common salt, and the impurities which rose to the surface removed by skimming. During the evaporation, a portion of common salt separated, and this being too impure for use, was reserved for the purpose of concentrating the brine in summer. The evaporated bitter liquor was then removed into wooden coolers 1 foot deep, where it remained 24 hours, during which time, in clear and cold weather, the sulphate of magnesia crystallized at the bottom, in quantity equal to about $\frac{1}{8}$th of the boiled liquor. The uncrystallizable fluid was then let off through plug holes at the bottom of the coolers, and the Epsom salt, after being drained into baskets, was deposited in the storehouse. This formed *single* Epsom salts, and after having been dissolved and crystallized a second time, it was termed *double* Epsom salts. Four or five tons of sulphate of magnesia were produced from a quantity of brine that had yielded 100 tons of common salt, and 1 ton of what is called *cat-salt.*[1] In some places, the bittern is decomposed by hydrate of lime, which is mixed with it in tanks, and the resulting precipitate afterwards treated with sulphuric acid, by which sulphate of magnesia and sulphate of lime are formed.

Hydrated sulphate of magnesia, $MgO,SO_3,7HO$, crystallizes at the ordinary temperature, in four-sided prisms, with reversed dihedral summits, or four-sided pyramids. They are doubly refracting, and their density 1·7. If the crystallization takes place at a high temperature, the salt contains only 6 equivalents of water, and if crystallized at a low temperature, (below 32°, for example,) large crystals are obtained, containing 12 equivalents of water. Heated to about 460° sulphate of magnesia still retains 1 equivalent of water, but loses it at a higher temperature. The anhydrous salt fuses at a red heat into a white enamel. The crystals are soluble in about their own weight of water at 60°, and in three-fourths their weight of boiling water, 100 parts of water at 32° dissolve 25·76 parts of the anhydrous salt, and for every degree above that temperature, they take up 0·26564 parts additional. Sulphate of magnesia is much more soluble in hydrochloric acid than in water. Exposed to air, the crystals when pure have a slight tendency to effloresce; and the salt of commerce will even deliquesce in consequence of the presence of a little chloride of magnesium. The salt of commerce is sometimes adulterated with small crystals of sulphate of soda, a fraud which may be detected by the

(1) Dr. Henry: Philosophical Transactions, 1810.

inferior weight of the precipitate of hydrated carbonate of magnesia occasioned by adding carbonate of potash.

Sulphate of magnesia combines with the alkaline sulphates, and with sulphate of ammonia, forming double salts, which crystallize easily.

Nitrate of magnesia is formed by dissolving white or calcined magnesia in dilute nitric acid: it is deliquescent and very soluble in water: it is entirely decomposed at a red heat, and leaves a residue of pure magnesia.

Carbonate of magnesia in its native form is known as *magnesite:* it is found in Piedmont and Moravia, and also in North America, in veins of serpentine accompanying the native hydrate. It also occurs in combination with carbonate of lime, with which it is isomorphous. Most of the calcareous rocks contain a small quantity of magnesia. The species of marble called *Dolomite*, which occurs abundantly in the Alps, contains about 40 per cent. of carbonate of magnesia; it is a double carbonate of lime and magnesia, $CaO,CO_2 + MgO,CO_2$. The *magnesian limestone* of Derby and Nottingham is generally of a yellowish colour: it dissolves less rapidly in dilute hydrochloric acid than the purer limestone, whence the French term it *chaux carbonatée lente.* It affords excellent lime for cements, but is not adapted to agricultural purposes, probably in consequence of the lime remaining caustic so long.

When an alkaline carbonate is poured into a solution of a salt of magnesia, a white gelatinous precipitate is formed, which is a hydrocarbonate of magnesia, or a combination of the hydrate and of the carbonate of magnesia. The proportions of these two compounds vary according to the quantity of alkaline carbonate employed, the strength of the solutions, and the temperature. This product is prepared in large quantities in pharmaceutical chemistry, and is the *magnesia alba* of the pharmacopœia. Two kinds identical in composition are prepared, viz. the *light* and the *heavy*. "For *heavy* magnesia, add 1 volume of a cold saturated solution of carbonate of soda to a boiling mixture of 1 volume of a saturated solution of sulphate of magnesia, and 3 volumes of water: boil until effervescence has ceased, constantly stirring with a spatula. Then dilute with boiling water, set aside, pour off the supernatant liquor, and wash the precipitate with hot water on a linen cloth: afterwards dry it by heat in an iron pot. *Light* magnesia is prepared by employing dilute solutions of the sulphate of magnesia and carbonate of soda. If no heat be used, it is apt to be gritty. A heavy and gritty magnesia is prepared by separately dissolving 12 parts of sulphate of magnesia, and 13 parts of crystallized carbonate of soda, in as small a quantity of water as possible, mixing the hot solutions, and washing the precipitate."[1] The light cubes of magnesia are prepared as follows:—A solution of 100 parts sulphate of magnesia in 100 of water is put into a vat heated by steam; a solution of 125 parts of crystallized carbonate of soda is quickly stirred into it, and the temperature raised to 176°, to expel carbonic acid, which holds some of the magnesia in solution: the liquor is then decanted off the precipitate, and this is washed three times by subsidence and decantation with luke-warm water, free from salts of lime: it is then transferred to linen strainers, and allowed to drip from 24 to 48 hours, and is transferred in a wet state to cubical boxes without bottoms, placed upon a table of plaster or porous stone, which quickly absorbs the water: after some time, the boxes are turned upside down, so as to present the upper side of the magnesia to the absorptive surface: the drying is completed in warm rooms.

The carbonate of magnesia of commerce is also prepared in various ways from bittern. It is also separated from magnesian limestone by a process adopted by Mr. Pattinson, which consists in calcining it at a dull red heat, by which the magnesian carbonate only is decomposed: the calcined stone is then diffused through water and subjected to the action of carbonic acid, under pressure, by which the magnesia only is dissolved and is afterwards obtained by rapidly boiling down the solution.

By passing a current of carbonic acid through a mixture of water and carbonate of magnesia, a clear solution is obtained, which, surcharged with carbonic acid, is a useful preparation, which has been extensively advertised under the name of *soluble magnesia*, or *bi-carbonate of magnesia*. This compound cannot be obtained in the solid or crystalline form, for the solution gives by evaporation oblique rhombic prisms of hydrated carbonate of magnesia, which, on being put into cold water are decomposed, carbonate of magnesia being dissolved, and a sub-carbonate deposited.

There are several phosphates of magnesia. The ammonio-magnesian phosphate is deposited from human urine, often in the form of white sand, or as a crystalline film: it also forms calculi. Phosphate of magnesia is present in the husk of grain, in the potato, and other plants; and the supply in the soil of phosphoric acid and magnesia is kept up by animal manures: phosphate of magnesia is also found in turf, ashes, and in good malt liquor.

Several silicates of magnesia occur in nature. *Meerschaum*, or *Ecume de Mer*, so much esteemed by the tobacco smoker, is a hydrated silicate of magnesia, MgO,SiO_3,HO; but as the compound is not crystalline, its constituents are variable, and silicates of iron and of alumina occur with it: these affect the colour of the meerschaum, which, when pure, is quite white. The presence of silicate of iron imparts a tint varying from pale yellow to deep brown. Good meerschaum is soft enough to be indented by the thumb nail: it yields readily to the knife, especially after having been wetted. The fracture is usually earthy, seldom conchoidal. The state of aggregation is so variable as to give rise to various densities: some kinds sink in water, others float on its surface: those of medium density are preferred by the pipe-maker, for the light varieties are porous, and even cavernous, and the heavier kinds are often made up

(1) Pereira: Elements of Materia Medica.

artificially. Most of the meerschaum is from Asia Minor: it is dug chiefly in the peninsula of Natolia, near the town of Coniah; but it is also found in Spain, Greece, and Moravia. It is exported in the shape of irregular blocks, with obtuse angles and edges. Much care is required in removing the irregularities and faulty portions, and even then it may contain various defects, such as different minerals diffused through it, and also a hard variety of meerschaum, called by the manufacturer *chalks* (*Kreidemassen*), which occasions much difficulty in the carving.

In some cases the meerschaum is roughly fashioned into bowls on the spot where the material is dug, and they are more elegantly carved in Europe. Pesth and Vienna were formerly celebrated for this manufacture. In forming a bowl, the meerschaum is prepared for the operation by soaking in a composition of wax, oil, and fats. The wax and oil absorbed by the meerschaum are the cause of the colour produced by smoking: the heat of the burning tobacco causes the wax and fatty substances to pass through the stages of a dry distillation, and becoming associated with the products of the distillation of the tobacco, are diffused through the substance of the bowl, and produce those gradations of tint which are so much prized. In some cases the bowls are artificially stained by dipping them, before being soaked in wax, in a solution of sulphate of iron, either alone or mixed with dragon's blood. The parings which are produced in roughing out the bowls are formed into what are called *massa-köpfe*, or massa-bowls: the parings are triturated to a fine powder, boiled in water, and moulded into blocks, with or without the addition of clay: each block is then cut into a bowl, but as it contracts considerably, it must be left some time to dry. There was a fine display of meerschaums in the Austrian department of the Great Exhibition. Composition pipe bowls and cigar tubes were also exhibited. Referring to these, the Jury Report states that "these bowls are distinguished from real meerschaums by their greater specific gravity, but there is no very certain test by which the real meerschaum can be distinguished from the composition, and many suppose that all the heavier descriptions are spurious, though there is no absolute proof of this being the case. A negative test may, however, be mentioned: the composition bowls never exhibit those little blemishes which result from the presence of foreign bodies in the natural meerschaum; therefore, if a blemish occur in a meerschaum bowl, which is very frequently the case, the genuineness of the bowl is rendered most probable; but as blemishes do not show until after the bowl has been used for some time, the test is not of much value."

Magnesian minerals are often soft and apparently greasy to the touch: they have seldom any lustre or transparency, and are generally more or less of a green colour. *Steatite* or *soap-stone*, *talc*, and *asbestos*, are examples. *Chrysolite* contains more than half its weight of magnesia. *Bitter-spar* contains 45 per cent. carbonate of magnesia, 52 carbonate of lime, and a little iron and manganese: it is generally of a yellowish colour and a pearly lustre, semitransparent and brittle. The finest specimens are from the Tyrol, but a variety found at Miemo in Tuscany is called *Miemite*. *Boracite* is a native borate of magnesia.

MAGNETISM is the science which treats of the phenomena exhibited by magnets, (such as the loadstone, or bars of steel, to which similar properties have been communicated;) of the reciprocal action of magnets upon each other; of the laws of the forces which they develop; of the methods of making artificial magnets; and of the magnetic phenomena exhibited by the globe which we inhabit. The term is derived from the Greek word, *μάγνης*, the loadstone, or native magnet, from *Magnesia*, a country in Lydia, where it was first discovered. Our limited space will not allow us to do more than just indicate a few of the leading points in this beautiful science.

The peculiar properties possessed by the natural loadstone, or magnetic iron ore, can be imparted to iron and steel without altering their other qualities, such as weight, hardness, &c. The most obvious of these properties is that of *attracting*, and in some cases *repelling* certain other bodies; but the most useful property of the magnet is its *directive power*, or that of pointing in a certain direction, when allowed to move freely. The attractive power of the magnet was known in Europe many centuries before its directive power, and it was not until the latter was understood that the compass conferred upon the art of navigation extended powers, by means of which the New World was discovered, the most distant parts of the earth were visited, explored, and peopled, and commerce became the true civilizer. This directive power of magnets depends greatly on their attractive power, respecting which it is necessary to make a few remarks. The power of attracting iron or steel does not belong equally to all parts of a magnet. If a loadstone be dipped into iron filings, they will not adhere to its whole surface, but chiefly to certain spots, of which there are never less than two; so also an artificial magnet (which is in the form of a long bar, either straight, or bent like a horse-shoe), displays no attractive power at its middle, but at its two ends that power is most strongly developed.

Now, although the two ends of a magnet attract equally, they possess a certain opposition of properties, which is called *polarity*, and on this account the two ends are termed the *poles*. This opposition may be observed by means of two artificial magnets, in each of which one end is distinguished from the other end by a notch. If the marked end of one magnet be presented to the unmarked end of the other, they will attract each other twice as strongly as either of them would attract common iron; but between two similar poles, whether both marked or both unmarked, there is no attraction, but on the contrary a *repulsion*, which, however, being weaker than the attraction, is not generally perceived unless one of the magnets be either floating or suspended by a fine thread attached to its centre, or poised upon a fine point by means of a small cup inserted into its centre. [See COMPASS.] When a straight and slender

steel magnet, called a *needle*, is so poised, as shown in Fig. 1375, and is not within the influence of any other magnet, or piece of iron, it always assumes a certain position in preference to any other, and this position is the same for all needles at the same place. Thus, all the magnetic needles in London that are not disturbed by wind or other forces, are now pointing with the marked end 23° west of north, and consequently the unmarked end 23° east of south, or nearly so. Their position varies by small fractions of a degree at different hours of the day, and different seasons of the year, and also undergoes a very slow but continual change from year to year. All these changes are subject to laws of great complexity, which cannot be said to be well understood.

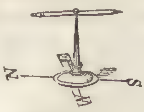


Fig. 1375.

Now, although the needle of a compass is commonly said to point north and south, such is not now the case in London, nor has been since the year 1658. Before that year the marked end of the needle pointed eastward of north, and ever since it has pointed westward; but this westerly *variation*, as it is called, reached its maximum, which was about 24½°, in 1815, and is now diminishing; that is, the needle is slowly reapproaching the *true meridian*, or north and south line. But the amount of this magnetic variation is very different at different places, and over one half of the world it is easterly instead of westerly. Hence, it is of great importance to navigation that its exact amount, and the laws by which it may be calculated at different spots, should be known. Fig. 1376 will convey a rough idea of the various directions which the needle assumes in different parts of the world. It will be seen that there are very few places where it lies on the meridian, or north and south, as at A and B; for while the meridians all tend to two points, or poles, viz. the ends of the earth's axis, the direction of the needle, or *magnetic meridians*, tends to two other points, only one of which is seen in the figure, marked by a black spot. This point is about 19° from the north pole, in the direction of Hudson's Bay; the other, or *south magnetic pole*, is in the continent of Victoria Land, and has been approached within 160 miles. On approaching either of these points, the needle must obviously vary greatly from the meridian, and change its direction rapidly. At the magnetic pole itself the needle shows no tendency to point in any direction, and between this and the true pole, the variation becomes more than 90°, so that the marked end of this needle, commonly called its *north pole*, becomes the southernmost. Thus the earth influences all the magnets on its surface, just as if it were itself a great magnet, having its unmarked pole north of Hudson's Bay, and its marked pole in Victoria Land; and this huge magnet, like all natural loadstones, has its power very irregularly distributed, so that the direction of the needle at any spot can only be exactly found by experiment; and lines passing through all the spots where it has the same direction, or *lines of equal variation*, are not regular, but very complex and irregular, curves. Nor is the *line of no variation* a regular meridian, but a waving circle, passing through both the true poles, and both the magnetic poles. In 1658 this line must have passed through England, but since that time it has shifted westward about a quarter of the earth's circumference, so that it now passes through the two American continents, and England is left nearly as far from it as possible. The other half of this line passes through Australia and China, and is gradually approaching us as the American line recedes from us; so that the magnetic poles seem to have a very slow westward revolution round the true poles of the earth.

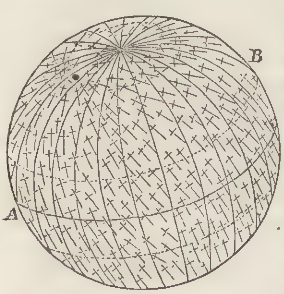


Fig. 1376.

As the directive tendency of the needle arises from its poles being attracted by those of the earth, it is evident, from the rotundity of the earth, that its poles will not pull those of the earth horizontally, but downwards, so that the needle cannot tend to be horizontal, except when acted on by both the earth's poles equally, that is, when it is midway between them. When nearer the north magnetic pole than the south, its north or marked end must be attracted downwards, and the contrary when it is nearest the south pole. Accordingly, a needle which was accurately balanced on its support before being magnetised, will no longer balance itself when magnetised, but, in this country, its north pole will *dip*, or appear to be the heavier end; and this has to be corrected in ships' compasses by a small sliding weight attached to the southern half, which weight has to be removed on approaching the equator, and shifted to the other side of the needle when in the southern hemisphere.

The dip of the needle may be illustrated by the following experiment:—Let N S, Fig. 1377, be a magnetic bar, 30 inches long, about ½ inch thick, and 1 inch wide, and let *n s* be a small magnetic needle, about 2 inches in length, suspended by a filament of untwisted silk, immediately over the magnetic centre *c*, so as to be a full length distant from it. At this point the needle will retain its horizontal position, its axis being parallel to the axis of the magnet beneath, and its poles *n s* in a reverse

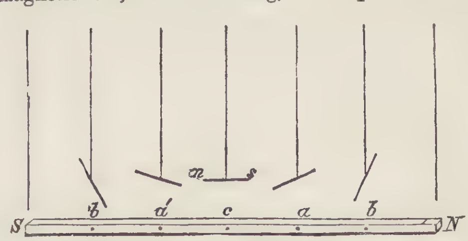


Fig. 1377.

position to the poles N S of the bar. Let this small needle be gradually moved along over the magnetic surface N S, and it will be found to take different degrees of inclination, the inclination being greater as we approach either pole N S, at which points it will be 90°. It will also be seen in the course of this experiment, that the south pole *s* dips on the north polar side of the centre *c*, and the north pole *n* on the south side.

In order to measure the dip with accuracy at any place, the needle is mounted so as to move freely in a vertical plane, instead of a horizontal one, as in the compass, or in Fig. 1375. An approved form of dipping needle, as constructed by M. Gambey, of Paris, is shown in Fig. 1378, in which N S represents a light magnetic bar, or needle, of a long lozenge form, about 10 inches long, which, before being magnetised, is set on a short axis *a a*, and is very accurately poised about its centre of gravity, through which the axis is passed, so as to remain indifferently in any position. The axis *a a* is turned down at its extremities to very fine cylindrical pivots: these rest on two finely polished agate planes *a a*, supported on two cross bars of a light rectangular frame F F′.

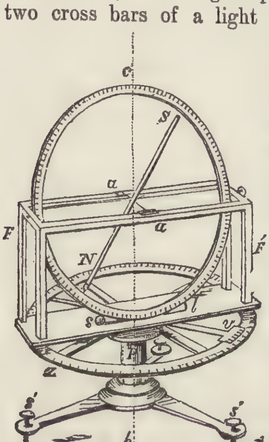


Fig. 1378.

The platform supporting this frame is solid, and fixed to a circular plate beneath, which is accurately ground to a similar plate fixed on a vertical pillar P, so that by means of a vertical axis, which plays in a socket in P, the whole may be turned evenly and centrally round into any azimuth. There is a spirit-level *s l* on the solid platform, which also supports a finely divided circle *s c l*, in the plane of which the bar N S moves. The axis *a a* is so placed as to pass accurately through the centre of this circle. The whole is mounted on the central pillar P, and can be turned into any required azimuth about a supposed vertical axis *c c′*, passing through the centre of the needle. The precise angular quantity through which the needle is turned, is measured by a vernier *v*, attached to the under part of the platform, and a graduated azimuth circle Z fixed to the pillar P. The whole is placed on a light but firm base, furnished with three levelling screws *s′*, for levelling the instrument. The vertical circle *s l c* is divided upon silver to 10′ of a degree. The agate pieces *a a* are adjustable to the same horizontal plane by screws bearing upon their lower edges, and there is a light interior frame acted on by a lever above F′, furnished with Y-pieces at *a a*, and moveable on an axis at one extremity F, by which the axis of the needle N S may be lifted off the agate planes *a a*, and be again let down on them without disturbing its final position. The whole is covered by a light case of wood and glass, resting on the platform (but not shown in the figure), in order to shield the needle from dust and air; and there are also two moveable arms attached to a horizontal bar, connected with the case, which carry lenses for reading off the degrees of the divided circle *s c l*.

In taking an observation with this instrument it must first be accurately levelled, and the graduated circle *s c l* then adjusted in the magnetic meridian. "This is effected either by removing the needle of inclination, S N, and placing a balanced horizontal needle, made expressly for the purpose within the frame F *a a* F′, or in any other situation adapted to it, or by turning the instrument so as to bring the needle into a vertical position. It will then be at right angles to the magnetic meridian; and we have then only to turn it 90° from this point, as shown on the azimuth circle Z. Having determined the direction of the magnetic meridian, the plane of the circle *s c l* is finally secured in that direction by a small clamp screw at P. We now remove the horizontal needle, if that be employed, and replace the needle of inclination S N, allowing it to vibrate freely. When it is at rest we turn the milled head lever above F′, and lift the axis *a a* gently off the agate planes by means of the Y-pieces: when again let down it will be accurately in the centre and in the plane of the divided circle. Supposing we had an absolutely perfect instrument, the needle would now mark the precise angle of inclination at the place of observation; but there are mechanical errors quite inseparable from the construction of the instrument, which we can only hope to compensate by a mean of experiments. We therefore, first, take a few successive observations, and note the angle at which the needle rests after putting it into vibration. This should be repeated with the axis *a a* reversed in position on the agates. We then turn the face of the instrument 180°, as shown by the circle Z, and make a similar number of observations. We now remove the needle N S, reverse its poles, and take a similar series of observations; so that we have then to take the mean of a given number of observations, say 10 :—

First, with the face of the instrument, suppose to the East.
Second . . . . to the West.
Thirdly, with inverted poles . face to the East.
Fourthly . . . . to the West.

The nearer these observations accord the more perfect is the instrument; but they will certainly differ by some small quantity. If we add the whole together, however, and divide by the number of observations, the resulting quotient will be very near the true inclination of the needle. Thus the inclination of the magnetic needle in the gardens of the Athenæum at Plymouth was found to be in November 1831, by Gambey's instrument, 69° 27′ 6″."[1]

In London, in 1830, the dip was 69° 38′. The various positions of the dipping needle at different parts of the earth's surface are represented in Fig.

(1) Sir W. Snow Harris, Rudimentary Magnetism, published in Weale's Series. This cheap work contains an admirable exposition of the science of magnetism.

1379. The *lines of equal dip* are much simpler than those of equal variation, and resemble parallels of latitude, only irregularly waving as here shown. The *line of no dip*, or the *magnetic equator*, deviates in some places 12° from the true equator; but it is not quite settled whether it crosses that line four times or only twice. But as it is dependent on the magnetic poles, it must, like all the magnetic lines, be gradually shifting westward and thus the dip, as well as the variation, at every place is constantly changing; that in England, for example, is very slowly diminishing. This angle, too, suffers very small changes, dependent on the hours and the seasons.

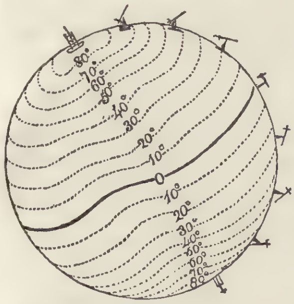


Fig. 1379.

There is also a third magnetic *element*, as it is called, which is subject to variation both from time and place; viz. the *intensity* of the force by which the needle is pulled into its peculiar position. This is found to be generally greatest near the earth's poles, and least at the line of no dip; but it varies irregularly over the surface. The importance of investigating its laws will be obvious when we consider that the great and increasing use of iron in the construction of ships, must draw their compass-needles out of the true position; and this would lead to error unless accurately calculated and allowed for. Now the less the effect of the earth's magnetism, the more will the needle be disturbed by the iron on board, so that to make the proper allowance, the variations of the magnetic intensity at different spots must be known. In order to determine the exact amounts and changes of these three magnetic elements, the *direction*, the *intensity*, and the *dip*, magnetic observatories have been erected, temporarily or permanently, in different distant spots on the earth's surface, in which long series of careful observations have been and are being made. In order to carry on similar observations near the magnetic poles, arctic and antarctic expeditions have been fitted out.[1]

The first great application of magnetism to the useful arts, is undoubtedly the Mariner's Compass, and second only in importance to it is the application of the magnetic needle to the Electric Telegraph. There are also a few minor applications which require a brief notice.

Dr. Scoresby has applied magnetism for the purpose of determining distance through matter which would be otherwiše impermeable, such as a solid rock, or other substance, and this method has been found useful in driving tunnels and in other mining operations. The principle of the application will be understood if we consider that, as the force of a magnet is measured by the deviations of a delicate needle under the influence of such magnet placed in the line of its centre at right angles to the meridian; so, conversely, the same deviations under similar conditions of direction, must correspond with equality of distance, supposing the intervening matter to be permeable or transparent to magnetism. If, therefore, we determine for a given magnet and needle, a table of deviations corresponding with certain distances between the centre of the needle and magnetic pole when placed in a given position, we may thereby determine the distance at which the magnet is operating through solid matter, by observing the deviation produced. For example: let C N M S, Fig. 1380, be a mass of solid rock, S N the direction of the magnetic meridian, and that the walls of the mass lie in that direction: let C be a delicate compass, finely divided and placed on one side of the rock, and M, a magnet placed perpendicular to its centre on the other: the compass-needle will then be deflected a certain number of degrees; from which the distance may be found either by the table, or by bringing the magnet round to one side of the compass, and finding experimentally the distance at which the same amount of deviation will be produced. If the intervening rock should lie oblique to the meridian in direction S N, and the compass-needle become oblique to the walls, we must then deflect it by the influence of an auxiliary magnet, so that it may stand parallel to the walls of the rock, and then proceed as before. By a careful preparation of the apparatus Dr. Scoresby has succeeded in measuring distances of 126 feet to within a very small fractional amount.[2]

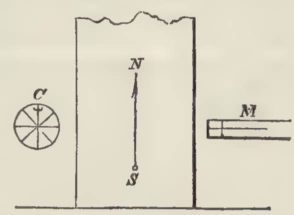


Fig. 1380.

Magnets are also employed for separating and collecting particles and fragments of iron mixed with other finely divided matter. It was also proposed many years ago to protect the dry grinders of cutlery from the noxious effects of the metallic dust which pervaded the air of the grinderies, by furnishing them with masks of magnetic steel wire, which it was thought would so filter the air as to deprive it of its noxious character. It is true that the magnetised wire would retain the ferruginous particles, and thus be of some service; but it would have no influence on the stone-dust from the grind-stones; this dust would enter the lungs of the men, and in the course of a very years produce organic disease. There may also be some truth in the statement, that the men refused to wear the masks, lest by removing the un-

(1) Sir James Clark Ross had the honour of discovering the north magnetic pole, and also of approaching within 160 miles of the south magnetic pole. An analysis of his southern expeditions is given in a small work compiled by the Editor, and entitled, "Summer in the Antarctic Regions; a Narrative of Voyages of Discovery towards the South Pole." Published under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge. 1848.

(2) Edinburgh New Philosophical Journal, 1832. Harris's Rudimentary Magnetism

healthiness of the occupation numbers should be attracted into it, and thus wages be diminished. At any rate, the only effectual remedy for the terrible evils of dry-grinding, is in efficient ventilation, as stated in our article CUTLERY.

In our INTRODUCTORY ESSAY, page ciii., reference is made to a method adopted in Canada, of separating the iron of certain rich ores from its gangue by means of magnets.

MAGNIFYING POWER. See LIGHT.

MAGNITUDE is that of which greater or less can be predicated when two of the same kind are compared together. The term is generally taken as synonymous with *quantity*, and is even applied to *number*. The answer to the question "How much?" describes the quantity, and the answer to "How great?" describes the magnitude. Magnitude in our language is usually applied to amount of space, hence quantity is the general term, and magnitude the quantity of space.

MAHOGANY (*Swietenia Mahogani*), the most important species of a small genus of plants named in honour of Gerard van Swieten, a physician of Leyden. It is a native of Campeachy and of the West Indies, where it is a lofty tree with a large spreading head and glossy pinnate leaves. The trunk frequently exceeds 40 feet in length, with a diameter of 6 feet. The timber, well known for its general use in furniture and cabinet making, is of a rich red-brown, of different shades and markings, capable of a brilliant polish, close-grained, very little liable to warp or shrink, and having a semi-resinous juice which preserves the wood from the attacks of insects. Mahogany is imported from several of the West India islands, and from the Spanish main. It arrives in logs about 10 feet long and 2 feet square. Honduras mahogany is imported in logs from 2 to 4, or even 6 feet square, and from 12 to 18 feet long. This variety is lighter in colour, and more open and irregular in grain than the Spanish. By some botanists the Honduras mahogany has been described as a different species; but it appears probable that differences of soil and situation have produced the variations in quality. There are woods called mahogany, brought from Africa and the East, but they belong to other genera, and are decidedly inferior to the true mahogany. A specimen of the latter, however, was sent from the Botanic Garden, Calcutta, to the Great Exhibition, and its fine quality proved that the true variety may be raised in the East Indies. The value of the best Spanish mahogany may be judged of by the fact, that the Messrs. Broadwood gave 3,000*l.* for three logs of fine mahogany, each 15 feet long and 38 inches square. These logs were the produce of a single tree. The wood was exceedingly beautiful, and when polished, it reflected the light in a varied manner, offering a different figure in whatever direction it was viewed. These logs were brought to this country with a full knowledge of their value; but, generally speaking, the purchase of this wood is a sort of lottery. Dealers in mahogany often introduce an auger before buying a log; but this does not always enable them to judge with precision respecting the quality of the timber. Honduras mahogany grows mostly upon moist low land, and is generally soft, coarse, and spongy. It has, however, the advantage of holding glue admirably, and is, in consequence, much used as a ground on which to place veneers of the finer sorts of mahogany. The cutting of mahogany at Honduras is carried on twice a-year—at Midsummer and soon after Christmas. The mahogany of Cuba and Hayti, and of the islands in general, is close-grained, dark-coloured, and sometimes highly figured: it is known as Spanish mahogany. The general appearance of the tree is extremely beautiful, and has been thus described:—"In the rich valleys among the mountains of Cuba, and those that open upon the bay of Honduras, the mahogany expands to so giant a trunk, divides into so many massy arms, and throws the shade of its shining green leaves, spotted with tufts of pearly flowers, over so vast an extent of surface, that it is difficult to imagine a vegetable production combining in such a degree the qualities of elegance and strength, of beauty and sublimity."

Mahogany may be safely pronounced the most useful of all furniture woods, for which it is particularly adapted on account of its size, abundance, durability, and beauty, and from the fact that it holds the glue better than any other wood. It is much used for founders' patterns, and other works in which permanence of form is of great consequence. It is also employed for a variety of turned works. Mahogany, in common with all other large foreign woods, requires to be carefully dried after it is cut into planks, as, notwithstanding the long time which may intervene between the felling and the using, it continues, so long as it is in the log, to retain much of its moisture. Well-seasoned Spanish mahogany cuts well, takes a brilliant polish, resists scratches, stains, and fractures much better than inferior sorts, and is worth the trouble and delicate workmanship which are often expended upon it. The colours are brought out by the application of oil or varnish, but much washing or soaking of the wood in water will destroy its beauty and render it of a dingy brown. The colour of mahogany is often artificially deepened by alkaline applications, but the best effect is produced by the use of a colourless varnish, which allows the natural tints of the wood to be displayed unaltered.

From the resemblance of the seed-vessel of the mahogany-tree to that of the Barbadoes cedar, the name of cedar has been sometimes erroneously applied to it. There is so far a correspondence in the nature of these trees that the mahogany, like the pine tribe, succeeds best upon the coldest soils and in the most exposed situations. When it grows on moist soils and warm lands, it becomes coarse and spongy, and the timber is not secure from the attacks of worms.

The first mention of this beautiful timber occurs in 1597, when it was used to repair some of Sir Walter Raleigh's ships at Trinidad. Yet the timber was not sent to this country until about the beginning of the last century, when a few planks brought over as ballast in a vessel from the West Indies, were

given to Dr. Gibbons, and would have been used, but for their hardness, by his workmen in erecting a house in Covent Garden. Having been rejected by them, a piece was given to a cabinet maker, named Wollaston, with the request that he would make a candle-box of it. This being done, the candle-box proved so beautiful that it became an object of curiosity, and the despised mahogany came into great request, and was soon established as a valuable material for household furniture.

MALACHITE. See COPPER—INTRODUCTORY ESSAY, page cxix.

MALIC ACID. This acid, first obtained by Scheele in 1784, from the juice of apples (whence the term from the Latin *malum*, an apple), is the most widely diffused of all the vegetable acids: it occurs partly in a free state and partly in combination with potash, lime, magnesia, and some organic bases. Unripe fruits owe their sour taste to the presence of this acid. It is usually prepared from the berries of the *Sorbus aucuparia*, or mountain-ash. The juice of the berries is obtained by expression, clarified by boiling with the addition of white of egg, and then filtering: a solution of acetate of lead is added, and the resulting precipitate washed with cold water: boiling water is next poured upon the filter, and allowed to pass through the precipitate into glass jars: after some hours crystals of malate of lead are deposited: these are boiled with 2·3 times their weight of dilute sulphuric acid of sp. gr. 1·090. The clear liquor is to be poured off, and while still hot, a stream of sulphuretted hydrogen is to be passed through it to precipitate the remaining lead: the liquid is then filtered, and when boiled so as to expel the excess of sulphuretted hydrogen, is a solution of the pure vegetable acid. The composition of malic acid is $C_8H_4O_8$, 2HO. By careful evaporation the liquid concretes into mamillary masses of imperfect aricular crystals. It is deliquescent and very soluble in alcohol and water. Nitric acid converts it into oxalic acid. It forms salts with bases. The malates are mostly soluble in water, but insoluble in alcohol, with the exception of the malate of the peroxide of iron. Malic acid does not render lime water turbid, but on evaporation crystalline malate of lime separates, which is redissolved by boiling. This serves to distinguish malic acid from oxalic, tartaric, racemic and citric acids. When malic acid is heated to 300° it is transformed into *pyromalic* acid, also known by the names *fumarric*, *lichenic*, or *paramalæic* acid, C_4HO_3,HO. It is found in the *Fumaria officinalis*, in Iceland moss, and other plants. Its salts are termed *fumarates*. At a temperature a little above 390° malic acid is converted into *malæic* or *mafuric* acid, $C_8H_2O_6$, 2HO. The salts of this acid are termed *malæates*.

MALLEABILITY. See METAL—ALLOY.

MALT. See BEER.

MALTHA. See ASPHALTUM.

MANGANESE, (Mn 28.) This simple metallic body bears some resemblance to the alkaline metals potassium, sodium, calcium, &c. in having a powerful affinity for oxygen, and attracting it from air and water with avidity: its oxides are very difficult to decompose, but they have none of the chemical properties of alkaline bodies; indeed, in its highest state of oxidizement, manganese forms acids. As a metal, manganese has seldom, if ever, been obtained in a state of chemical purity: the purest specimens have been found to contain carbon. The metal is obtained by reducing one of its oxides by means of carbon at a high temperature. It is described as a grey metal, possessing a certain amount of ductility; it can be filed, but breaks under the hammer; it resembles in its colour and fracture certain varieties of cast or pig-iron. Its density is about 8. It decomposes water rapidly at 212°. To preserve it from the oxygen of the air it is kept in naphtha, or, still better, in a glass tube hermetically sealed.

There are five compounds of manganese and oxygen, of which three are oxides and two acids: there are also two intermediate oxides, the red oxide and the mineral named *Varvicite*. The *protoxide of manganese*, MnO, may be obtained by passing a current of dry hydrogen over the deutoxide or peroxide of manganese, contained in a porcelain or iron tube exposed to a heat which is to be gradually raised to bright redness: water is formed, and a dingy green powder, which is the protoxide. There are other methods of procuring it, for a description of which we must refer to chemical treatises. It is soluble in dilute acids, and is the basis of the ordinary manganesian salts. If caustic potash be poured into a solution of one of its salts, a white precipitate is obtained, which is the *hydrate of the protoxide:* it absorbs oxygen rapidly from the air, and changes into the hydrate of the sesquioxide. The *sesquioxide*, also known as *manganic oxide* or *deutoxide of manganese*, Mn_2O_3, may be procured by exposing the protoxide or carbonate of manganese to a red heat in an open vessel, when it absorbs oxygen and is converted into a deep-brown powder; or by exposing the protonitrate of manganese to a red heat the sesquioxide is left as a black powder. This oxide differs in its behaviour to solvents with its state of aggregation. It gives a violet, or in small portions, a pink tinge to glass, and is said to be the colouring matter of the amethyst. It also forms the mineral termed *braunite*. The *hydrated sesquioxide of manganese* Mn_2O_3+HO, may be obtained by exposing the hydrated and moist protoxide to the action of air. It forms the *manganite* of mineralogists. *Binoxide*, or *peroxide of manganese*, MnO_2, also called the *black oxide*, is the common *ore* of manganese, and is the usual source of the other combinations of this metal. Before its nature and composition were known, it was called *magnesia nigra*, from its resemblance to the loadstone; and indeed it was long included among the ores of iron. It is found in Devonshire, Somersetshire, and Aberdeenshire, in various forms, compact and massive, pulverulent and crystallized. Its sp. gr. is 4·8 to 4·9. It forms the *pyrolusite*[1]

(1) Πῦρ, *fire*, and λύειν, *to set free*, or *loosen*, from the facility with which it evolves oxygen under the influence of heat. Graham refers the origin of the term to the common use of manganese as a *glass soap*, from πῦρ, *fire*, and λούειν, *to wash*, in discharging colour from glass. [See GLASS.]

of mineralogists. It is sometimes contaminated with small portions of carbonate of lime, silica, oxide of iron, baryta, and some other substances. It is largely used in science and the arts as a source of oxygen, and in the manufacture of bleaching powder. It is used to give the black colour to earthenware, and it is said to have the property of sweetening foul water, or preventing it from becoming putrid. At a red heat it loses oxygen and becomes converted into the sesquioxide. [See OXYGEN.] It is a good conductor of electricity. It does not combine with the acids; but those acids which appear to dissolve it reduce it to the state of protoxide. Heated with hydrochloric acid, chlorine is evolved. [See CHLORINE.] A *hydrated peroxide of manganese* is formed by precipitating protochloride of manganese by chloride of lime. The soft black mineral, called *wad* by the miners, is a hydrated peroxide. *Red oxide of manganese*, Mn_3O_4, occurs native, and forms the mineral termed *Hausmannite*. A peculiar oxide of manganese has been found at Hartshill in Warwickshire, to which the term *Varvicite* has been given from its locality. *Manganic* or *Manganesic acid*, MnO^3. "When peroxide of manganese is heated to redness with nitrate of potassa, a compound is obtained, which, when put into water, furnishes a solution exhibiting various tints of green, purple, and red, and which was therefore called *Chameleon mineral*. A similar compound is more perfectly obtained by fusing the peroxide with caustic potassa at a red heat, which furnishes a green substance when the alkali is in excess. With water it affords a deep green solution of manganate of potassa, which is permanent with excess of alkali, but otherwise becomes blue, purple, and ultimately red on exposure to the air, in consequence of the formation of permanganate of potassa by the absorption of oxygen; at the same time it deposits a brown powder, which is hydrated peroxide of manganese, and free alkali is separated."[1] Manganic acid has not been isolated. *Permanganic* or *hypermanganic acid*, Mn_2O_7, has been isolated as a hydrate by various processes, one of which is as follows:—A manganate of baryta is first formed by heating nitrate of baryta with peroxide of manganese to redness; the green powder, thus formed, is reduced to a fine powder, mixed with water and a little dilute sulphuric acid added, by which a red solution of permanganate of baryta is obtained: this is concentrated by evaporation and carefully decomposed by sulphuric acid; the supernatant solution of permanganic acid is then decanted off. "The aqueous solution of permanganic acid is of a splendid carmine colour, or by transmitted light, dark violet: its taste is austere and bitterish: it tinges the skin brown, and gives the same tint to litmus and turmeric paper, depositing hydrated peroxide: it is soon decomposed at a boiling heat, and by the greater number of combustible bodies at common temperatures. Its salts, which are of a fine red or purple hue, are more permanent than the hydrated acid: they deflagrate with combustibles; they are all soluble in water, and many of them deliquescent."—*Brande.*

(1) Brande's Manual of Chemistry. This work contains a full account of the compounds of manganese and their applications; but the most ample account is in the fourth volume of Mr. Watts's excellent Translation of Gmelin's Handbook of Chemistry, published by the Cavendish Society, 1850.

There are three *chlorides* of manganese; an *ammonio chloride* and a *chlorate;* an *iodide* and an *iododate;* a *bromide* and a *bromate;* two *fluorides;* a *nitrate* and a *sulphuret*. The *sulphate* of manganese, MnO,O,SO_3 is much used in dyeing and calico printing, for which purpose it is prepared, according to Graham, by igniting peroxide of manganese mixed with about one-tenth its weight of pounded coal in a gas retort. The peroxide thus formed is dissolved in dilute sulphuric acid with the addition, at the end, of a little hydrochloric acid; the sulphate is evaporated to dryness and again heated to redness in the gas retort; the iron is found after the ignition in the state of peroxide, and insoluble, the persulphate of iron being decomposed, while the sulphate of manganese is not injured by the temperature of ignition, and remains soluble. The solution is of an amethystine colour, and does not readily crystallize. When cloth is passed through sulphate of manganese and afterwards through a caustic alkali, protoxide of manganese is precipitated upon it and rapidly becomes brown in the air; or it is at once peroxidized by passing the cloth through a solution of chloride of lime. The colour thus produced is called *manganese brown.*

A *sesquisulphate of manganese*, $Mn_2O_3+3SO_3$, is formed by dissolving the sesquioxide in sulphuric acid: the solution is of a crimson colour: when heated it gives off oxygen and becomes colourless. With sulphate of potash or ammonia it forms double salts crystallizing in octohedrons: these are *manganese alums:* they are similar in constitution to the ordinary alum, but with Al_2O_3, replaced by Mn_2O_3.

Manganese forms several compounds with phosphorus. It also combines with carbon, and it is said that the quality of steel is improved by the presence of carburet of manganese. A substance resembling plumbago, occasionally produced in iron furnaces, and called *kish*, is said to consist chiefly of carburet of manganese. A *carbonate* of manganese is precipitated as a hydrate, by alkaline carbonates, from the protochloride or protosulphate. There is also a native carbonate, or *spathose manganese*, MnO,CO_2. Manganese also combines with cyanogen and boracic acid.

Most of the salts of manganese containing the protoxide are soluble in water: the solution is colourless or (unless quite pure) slightly pink, of a bitterish astringent taste, and often becomes turbid and brown by exposure to air. They are not precipitated by sulphuretted hydrogen; they furnish white precipitates with the alkalis, which become discoloured by exposure: the alkaline carbonates throw down white precipitates, which change to purple; they are precipitated white by ferrocyanide of potassium, and flesh-coloured or reddish brown, by hydrosulphuret of ammonia. If peroxide of lead be heated with dilute nitric acid and a solution of manganese added, the liquid assumes the purple tint of permanganic acid

which becomes very evident as the peroxide subsides; minute traces of manganese may be detected in this way. Manganese and its compounds are also readily detected by blow-pipe tests.

MANGEL-WURZEL. See BEET—SUGAR.

MANGLE. See CALENDERING.

MANHEIM GOLD. See BRASS.

MANNA. See SUGAR.

MANOMETER, from μανὸς, *thin* or *rare*, and μέτρον, a *measure*, an instrument for measuring the rarity of the atmosphere, or other gas. The rarity of a gas is proportional to its elastic force, and so long as the temperature and chemical composition of a gas remain undisturbed, it is sufficient to construct the instrument so as to measure the elastic force of the gas under examination. The simplest form of this instrument was *Boyle's statical barometer:* it consisted of an exhausted glass globe, suspended from one arm of a delicate balance, and counterpoised by a metallic weight at the other, the adjustment being made when the mercurial column of a common barometer marked 30 inches, showing the air to be in its state of mean density. As the globe displaced its own bulk of air of mean density when it was counterpoised, it is evident that any variation in the density of the air would disturb the equilibrium, an increase of density causing the globe to ascend, and a diminution causing it to descend.

For the correction of barometric observations, manometers, consisting of glass tubes of various sizes, resembling thermometer tubes, have been employed. Such are the manometers of Captain Phipps and Colonel Roy. Those of Colonel Roy were from 4 to 8 feet long, with bores from $\frac{1}{15}$th to $\frac{1}{25}$th inch in diameter. The bulb and part of the tube being filled with air of known tension, and the rest of the tube with a short column of mercury, sufficient to cut off the communication between the outer air, and the air enclosed in the tube; it is evident that any change in the density of the outer air would be accurately measured by the ascent or descent of the mercurial column; for when the elastic tension of the surrounding atmosphere exceeded that of the air in the tube, the column would move towards the bulb, and *vice versâ*. If, however, the change in the tension of the atmosphere were partly due to a change of temperature, the motion of the column would merely measure the difference of the variations in the tension of the internal and external air, since the tension of both would be greatly affected by the change of temperature. The bulb was pear-shaped, and the point being occasionally opened, dry or moist air could be admitted, and the bulb sealed again without any sensible alteration in its capacity. From the adhesion of the mercury in the tube, it was necessary, in order for the instrument to act truly, to keep it in a vertical position.

A more convenient form of instrument is the *siphon-barometer*, the basin of which is enclosed, air-tight, in a globular vessel furnished with a number of cocks, by means of which and the air pump, or exhausting and condensing syringe, the gas contained in it may be removed, and some other gas substituted. If equal weights of different gases be introduced in succession, they will not be affected by any change in the surrounding atmosphere, except with respect to temperature; and provided the temperature remain constant, the relative tensions of these gases will be accurately measured by the weight of the mercurial column, suspended in the longer arm of the barometer, above the level of the mercury in the basin, the same precautions being used as in the barometer, to allow for differences in the level of the mercury in the basin, from variations in the height of the column.

If the air be pumped out from the receiver surrounding the bason of the barometer, and a small quantity of any liquid be introduced, it will be converted into vapour, the elastic force of which may be measured in the same way as that of permanent gases. The receiver may be made large enough to contain animals, or plants, and their effect in increasing or diminishing the tension of the enclosed gas, is measured by the rise or fall of the mercury. The exact determination of the elastic force of steam,

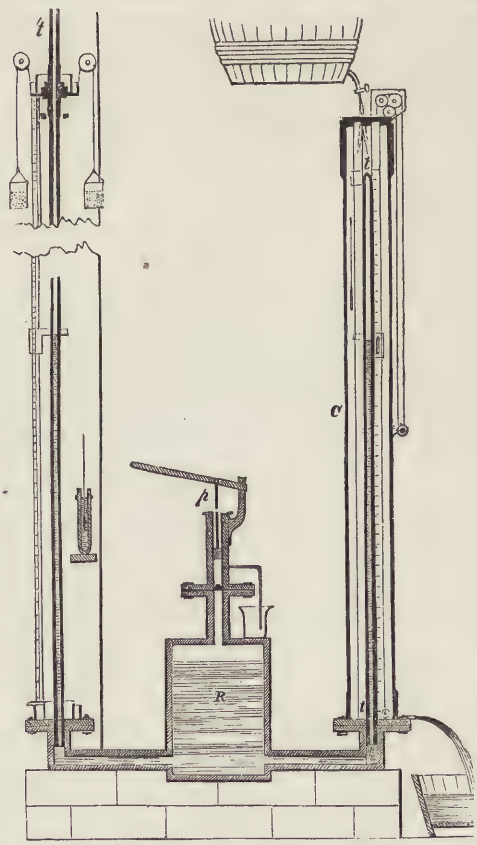


Fig. 1381. ARRANGEMENT OF MANOMETER.

at high temperatures, was undertaken some years ago by the Royal Academy of Sciences, at the request of the French government, and the Report of the Commissioners, MM. de Prony, Arago, Girard, and Dulong, is contained in the 43d vol. of the Annales de Chimie. The manometer used in these experi-

ments was a straight glass tube *t t*, Fig. 1381, of uniform bore, 1·7 mètres (67 inches) long, and 5 millimètres in internal diameter and the same in thickness, closed at the upper, and open at the lower extremity. The capacity having been accurately determined, it was filled with dry air of known density, and enclosed in a cistern of water C kept at a uniform temperature by water constantly pouring into it, and escaping at the lower extremity, as shown in the figure. Another tube of equal bore and thickness, *t'*, 26 mètres (85 feet) in length, and open at both ends, was then erected, and the lower extremities of the two tubes were made to communicate with apertures in the opposite sides of a cylindrical reservoir R, capable of holding about 1 cwt. of mercury. On the top of this reservoir was a forcing pump *p*, by which the pressure upon the surface of the reservoir could be increased as desired; and the increased pressure being transmitted to the lateral apertures, caused the mercury to rise unequally in both tubes: in the longer tube it rose until the weight of the mercurial column, together with that of the superincumbent atmosphere, were equal to the pressure; but in the shorter tube only until this pressure was counterbalanced by the rapidly augmenting expansive force of the confined air, added to the weight of the small column of mercury forced into it. The expansive force of the compressed air was measured by the difference between these two columns; and the shorter tube was carefully graduated so as to correspond to pressures varying from 1 to 29 atmospheres. In this way the manometer having been formed, the longer tube and the forcing pump were removed, and instead of the latter, the actual pressure of steam at successively increased temperatures was substituted, the tension of which was indicated by the compression of the air in the manometer.

MAP, (Latin *mappa*, a napkin,) a representation of the surface of a sphere, or a portion thereof on a plane. Although the term is usually applied to representations of the earth's surface, *terrestrial* maps, yet we have *celestial*, or *astronomical* maps to represent the sphere of the heavens. Terrestrial maps are of two kinds, *geographic*, or *land* maps; and *hydrographic*, *sea* maps, or *charts*. Where a land map describes the nature of the ground, the roads, buildings, &c. in detail, it forms what is called a *topographic* map, or *plan*. Some maps of the earth are made to illustrate its natural history, and then we have a *geological*, *mineralogical*, or *botanical* map.

A description of the methods of constructing maps scarcely belongs to a work devoted to Useful Arts and Manufactures; we must therefore refer the reader to some special treatise on the subject.

MAPLE, (*acer*,) is a tree of which there are numerous species, two of which are especially valued, the one on account of its timber, the other on account of its sugary sap. The great maple, known also as the *sycamore* and the *plane tree*, is of rapid growth, and has close and compact timber, not liable to warp or splinter. It is prettily marked and mottled; it takes a fine polish, and bears varnishing well; therefore it is much employed by the musical instrument maker. The best specimens, especially those from Prince Edward's Island, known as *bird's-eye maple*, and mottled maple, are used for picture frames, and other ornamental articles. Wooden platters, bowls, &c. are made of maple, and as this wood does not contain those hard particles which are so injurious to tools, it is employed as cutting boards; also, on account of its not being apt to warp either with changes of heat or moisture, it is employed for saddle-trees, founder's patterns, and many other useful purposes.

Bird's-eye maple has a peculiar dotted appearance, similar to that which is produced by knots in other woods. This appearance is thus accounted for by Mr. Holtzapffel:—"On examination I found the stem of the American bird's-eye maple, stripped of its bark, presented little pits or hollows of irregular form, some as if made with an irregular punch, others ill defined, and flattened like the impression of a hobnail. Suspecting these indentations to arise from internal spines, or points in the bark, a piece of the latter was stripped off from another block, when the surmise was verified by their appearance. The layers of the wood being moulded upon these spines, each of their fibres is abruptly curved at the respective places, and when cut through by the plane, they give, in the tangential slice, the appearance of projections; the same as in some rose-engine patterns, and the more recent medallic glyptographic, or stereographic engravings, in which the closer approximation of the lines at their curvatures causes those parts to be more black, or shaded, and produces upon the plane surfaces, the appearance of waves or ridges, or of the subject of the medal. The short lines observed throughout the maple wood, between the dots or eyes, are the edges of the medullary rays, and the same piece of wood, when examined upon the radial section, exhibits the ordinary silver grain of the sycamore, (to which family the maple-tree belongs,) with a very few of the dots, and those displayed in a far less ornamental manner. The piece examined measured 8 inches wide, and 5½ inches radially, and was apparently the produce of a tree of about 16 inches diameter; the effect of the internal spines of the bark was observable entirely across the same, that is, through each of the 130 zones of which it consisted. The curvature of the fibres was in general rather greater towards the centre, which is to be accounted for by the successive annual depositions upon the bark, detracting in a small degree from the height or magnitude of the spines within the same, upon which the several deposits of wood were formed. Other woods also exhibit spines, which may be intended for the better attachment of the bark to the stem, but from their comparative minuteness they produce no such effect on the wood as that which exists, I believe exclusively, in the bird's-eye maple."

MARBLE. The definition of this word is not very exact. In a vague sense, the term *marbles* is applied to numerous ornamental stones; but the typical or calcareous marbles may be considered as such primi-

tive, transition, and purer compact limestones of secondary formation, as can be quarried in solid blocks without fissures, and as are capable of a high polish. A limestone which admits of being worked easily and equally in all directions is called *freestone*, but a rock of similar chemical composition, capable of being worked in all directions, and also of taking a good polish, deserves the title of marble. The whiter, or more beautifully variegated the marble, the greater is the estimation in which it is held: when fine, white, and granular, it is valuable for the higher purposes of sculpture.

Marble, in all its varieties, consists essentially of carbonate of lime: it is characterised by its effervescence with acids, its conchoidal scaly fracture, and its translucence at the edges. It affords quicklime by calcination: it has a specific gravity of 2·7, and it can be scratched with a knife. Primitive marble is the most esteemed; it is distinguished from the secondary by the absence of organic remains, by its granularly foliated character, and by its occurrence among other primitive substances. The most celebrated statuary marble of ancient times was that of Paros near Athens, and some of the finest antique sculptures are wrought in it. The Italian marbles are also highly prized, especially the milk-white marble of Carrara or Luni, near the gulf of Genoa. An interesting notice of the marble quarries of Carrara appeared in a recent number of the Illustrated London News, from which we select the following particulars:—The magnificent chain of mountains in which the quarries are situated, juts out in an acute angle from the Apennines, and forms a portion of the duchy of Massa-Carrara. The aspect of these stupendous and "marble-hearted" heights, as seen from the sea-shore, whence they are distant about four miles, is highly picturesque. Almost destitute of vegetation, they gleam in the sun-light like masses of brass, while at intervals rugged and inaccessible peaks jut out sharply against the sky, and appear to pierce into the clouds. In numerous directions, about midway up the heights, the eye is attracted by what seems to be a vast torrent pouring down its resistless volume of seething water into the valley; but which is, in fact, the shoot of the refuse flung out of the quarry immediately above. On the flank of a few of the mountains, and near their base, some stunted vegetation, consisting mostly of dwarfed oaks and chestnut-trees, may occasionally be seen; while nearer to the summit, in the fissures and gulleys, a sickly and scanty herbage affords sustenance to troops of goats. The quarries are generally situated about midway up the mountain, and although they are said to have furnished the ancients with the material for building the Pantheon at Rome, and more recently to have supplied nearly every civilized country throughout the globe with their precious contents, to the extent of an export amounting annually to an average of 40,000 tons, the workmen are still employed upon the surface; and so little effect has the labour of centuries produced upon the general appearance of the mines, that they may be safely affirmed to be inexhaustible.

Of this export, the United States consumes nearly the whole. Italy, France, and England confine themselves almost entirely to the statuary marbles: England imports about 6,000 tons annually, but is steadily increasing its demand. Russia employs these marbles on her palaces and churches. The recent reduction of the import duties, which were formerly very heavy in some countries, cannot fail to increase the demand throughout Europe. There is, however, still a heavy export duty, which has, moreover, most injudiciously been lately increased by the native government.

The quarries of Carrara contain four varieties of marble, of which the most valuable is that used by sculptors, the *white granularly foliated limestone*. This was the favourite material of the artists of ancient Greece, and still is so of modern Europe, on account of its purity of colour, its delicate transparency, and its granular texture, which renders it much more easy to work than compact limestone. The two great sources whence the statuary marble of Europe has been procured are Paros and Carrara. The Parian marble is the most pure, consisting almost entirely of carbonate of lime, and is, consequently, softer, somewhat more transparent, and of a more visibly laminated texture than that of Carrara, which is frequently mingled in considerable proportion with granular quartz. The latter has, however, no other rival as regards either quality or durability. The other three varieties obtained are the *veined* marble, equal as regards texture to that already described, but traversed by coloured lines which render it inappropriate to the chisel; the *ravacioni* or Sicilian, similar to that produced near Messina; and the *bardiglio*, which is of a deep blue colour, but in formation precisely similar to the white.

Some of the quarries may be explored with ease and safety, but such is by no means the case with all of them; while, in every instance, the paths by which they are approached are dangerous to the uninitiated. At times almost perpendicular, the way leads along the brinks of stupendous precipices, where no path can be discerned. The miners are a fine and hardy race, remarkable for their robustness of constitution, reckless courage, and unalterable good humour; nor do the fatal accidents which occasionally occur tend to lessen their gaiety; many a snatch of wild but melodious song may be heard amid the clanging of hammers, the report of gunpowder, and the crash of falling stone. The hours of labour are from eight in the morning to two in the afternoon, all extra work being remunerated according to the time employed. There being no springs in the quarries, and the difficulty of ascent rendering it essential to the workmen to avoid all unnecessary burthens, they drink rainwater, which they obtain by excavating square holes as reservoirs; their diet consists of *polenta*, or bread, and the common cheese of the country; and these simple aliments, with the fruits of the season, compose their whole nourishment. In wine or coffee they never indulge; and yet they are capable of enduring a large amount of labour. In working the quarries, the huge blocks are first loosened from the mass by blasting,

after which wedges are applied until they are thoroughly detached from the rock, when they are shaped into oblong squares—with the exception of the statuary marble, of which the value is so great that the masses are removed intact—then lowered to the *poggio*, or base of the mountain, whence bullock-cars transport them to the Marina, where they are embarked. When the quarry is situated so perpendicularly that the stones incur risk of breakage from a too rapid descent, they are surrounded by strong ropes, and placed upon two parallel beams (or *lizzi*) of oak, beneath which lesser beams are arranged transversely. A workman stands upon the block throughout its perilous transit, and it is his duty to raise each of these so soon as it is passed, and to hand it to another man in front, in order that it may again be placed securely upon the passage of the descending mass. This is the most dangerous service performed by the miners, as it occasionally happens that the huge block, after shivering for an instant upon its wooden support, yields to the impetus of its own weight, and sliding from its oaken cradle, rushes headlong down the declivity, rending the stout cables by which it is bound, and crushing beneath its stupendous mass the unfortunate individuals employed in assisting its descent. Where the quarry is level, and nearer to the base of the mountain, the *lizza* is dispensed with, and the blocks are allowed to roll down unaided. At the *poggio* the blocks thus collected are loaded upon strong uncouth-looking bullock-cars, composed of three parallel beams of oak, of which the centre one is rather lower than the others; the animals are attached to the carriages in numbers proportioned to the bulk of the stone and the impediments which encumber their path. It is a very common occurrence to see ten yokes of oxen harnessed to one car, each guided by a driver, whose business it is to avoid as much as possible the ponderous masses which encumber the ground; and yet, at the first glance, it is impossible to believe that they can ever hope to accomplish so arduous an undertaking. In vain do the sturdy and patient brutes strain to their task; the couples can seldom or never be made to follow the guidance of their leaders, who, by stumbling and straggling over the rocky fragments among which they are impelled by their drivers, partially level the path behind them, as they are now dragged by the horns, now goaded by the iron-shod staff, and now urged by the wild, half-frantic cries of the men, whose shouts are re-echoed by the rocks in deafening dissonance; but, swerving to the right or left, hew out for themselves a new line of road frequently so impassable that, after having by a mighty effort overcome some apparently impracticable difficulty, the wretched animals stagger a few paces further, and then fall dead at their task. For this evil no remedy has yet been found: the nature of the ground, and the constant deposits of stone, rendering it difficult to construct a safer means of exit from the *poggio*. This marble range extends over many square leagues; the most productive, as well as the most valuable quarries, being those of the statuary marble, which do not exceed 12 in all, the whole of which are the property of four or five of the principal families of Carrara; but the aggregate number may be computed at 400, of which, between 40 and 50 are in full work, and produce admirable stone; while the number of workmen constantly employed varies from 2,000 to 2,500. Legends of gnomes and genii are rife among the miners, who, like their fellow-labourers in every land, are imaginative and superstitious; and in the quarry of Fantiscotti a number of names cut into the rock, and some roughly-carved figures hewn upon its surface, are objects of peculiar awe from the fact of their great antiquity, and the absence of all tradition regarding their origin.

Beautiful secondary marbles occur in Derbyshire, in Westmoreland, Devonshire, and Anglesea. Fine varieties occur in Sutherlandshire and in the Western isles of Scotland. Ireland boasts its Kilkenny marbles. Much of the carboniferous and transition limestone of Wales is also capable of being worked up into agreeable dark marbles.

The various marbles have been classed, by Brard, according to the several localities in which they are found, and in each of such classes he introduces 8 subdivisions, viz. 1, *Uni-coloured* marbles; including only the white and the black; 2, *Variegated* marbles; those with irregular spots or veins; 3, *Madreporic* marbles, presenting animal remains in the shape of white or grey spots, with regularly disposed dots and stars in the centre; 4, *Shell* marbles, with a few shells interspersed in a calcareous base; 5, *Lumachella* marbles, entirely composed of shells; 6, *Cipolin* marbles, with veins of greenish talc; 7, *Breccia* marbles, formed of a number of angular fragments of different marbles, united by a common cement; 8, *Pudding-stone* marbles, a conglomerate of rounded pieces.

Specimens of marble, both in the rough and manufactured state, were numerous in the Great Exhibition: probably on no other occasion were so many examples of this beautiful stone brought together. The working of marble into forms intended for household decoration involves the artistic skill of the sculptor and the ingenuity of the mechanic. It is remarked in the Jury Report of Class XXVII. that "Italy is pre-eminently the country where this manufacture has been found most congenial to the artistic feeling of the mass of the people;" but that of late years France, Spain, Portugal, and parts of Germany and Belgium have employed for their own use, and in their own style, many useful and valuable marbles with which they abound; that in Derbyshire, Devonshire, and Cornwall, the marble of those counties has been employed in house decoration, at a somewhat high cost, by yet at a much cheaper rate than it could be supplied from abroad. The marbles of Ireland are also getting into request. The green Connemara marble was conspicuous in the Exhibition for its rich green hue and great beauty. Among the marbles exhibited some were from Greece and Asia Minor, from the quarries worked by the ancients, now either exhausted or concealed by rubbish. Among these were the true *Parian* of Greek sculptors, and some other fine white

marbles: the *nero antico*, now a very rare black marble, considered to be purer and better than the known kinds; the *rosso antico*, a deep blood-red marble, with veins and spots; the *verde antico*, a green and very beautiful porphyritic brecchia; the *giallo antico*, not unlike the modern Sienna marble, of very rich yellow tint. Many, if not all these colours, are closely approximated by recent marbles.

The most important marbles of Derbyshire are the *black*, the *rosewood*, the *encrinital*, the *russet* or *bird-eye*, and a *mottled* dark and light-grey kind, occasionally containing numerous small corals. Of some of these there are several varieties. In addition to those found in the northern part of the county is one of a beautiful *red*, resembling the *rosso antico*, but it can only be obtained in small blocks or lumps.

Of the above varieties *black* marble is of very fine colour and texture; but large slabs, free from veins of calcareous spar, are rare. The best quality occurs in beds of from 3 to 8 inches thick; but some beds are thicker. It is tough, and contains a good deal of carbon, which imparts the colour. It is greatly valued for inlaying, and it has even been exported to Florence, Malta, and St. Petersburg. Black marble is used for vases, pedestals, chimney-pieces, &c. It is occasionally ornamented by etching and engraving, in which processes the polished surface is removed, and the brown colour of the rough marble exposed. Powdered white lead is sometimes rubbed into the etched surface, to increase the effect. The French have a method of ornamenting marble in this way by etching by acids deeply into the marble various designs upon a properly prepared bituminous ground: when the corrosion has gone sufficiently deep, the cavities are filled up with hard coloured wax, prepared so as to take a polish equal to that of the marble, when cleared off. Drawings thus made on black marble, and filled in with scarlet wax, after the manner of Etruscan, have a fine effect, and are used for tables, panelling, stoves, &c.[1] At Derby they succeed in exposing the brown colour without destroying the polish, the effect of which is more durable than ordinary etching. *Rosewood* marble, so called from its marking resembling that of rosewood, is extremely hard and of close texture. The beds are of considerable thickness, but the most beautiful part of the marble is only about six inches thick. The *encrinital* marble is the one in most extensive use; it contains numerous fossils, consisting chiefly of the broken stems of encrinites, often entangled in coral. It may be obtained in blocks of large superficies, and from two to two and a half feet thick. The *russet* or *bird-eye* takes its name from its colour and appearance,—the shades, varying from light grey to brown: it contains numerous minute encrinital fossils, and is found in beds of from 6 to 18 inches in thickness. The dark and light *mottled* grey marble, called *Newburgh* marble, and the overlying bed, which is coralline, can be obtained from one to two feet thick.

The marbles of Devonshire belong to an older geological period than those of Derbyshire, the latter being exclusively of the carboniferous limestone series, underlying the coal measures and the millstone grit; while the former are of the Devonian, or middle Palæozoic epoch. The Devonshire marbles are, in general, less manageable than those of Derbyshire. The most beautiful marbles of the county, especially those near Plymouth, are described in the Jury Report as being fossiliferous, brittle, and very apt to contain veins and cracks.

The principal marble manufacture of England is in Derbyshire, along the valley of the Derwent and the Wye, from below Buxton to Derby. The machinery for sawing and polishing was first established at the village of Ashford, near Bakewell, in 1748, water being the motive power. About the year 1810 similar machinery was erected at Bakewell. Both these works are situated near the quarries. Within a few years other works have been established at Buckland Hollow. There are also other works at Derby.

The first step in the treatment of marble is the dividing it into blocks or slabs of convenient size. This cannot be done, as in the case of the ordinary soft stones, with toothed saws of reciprocating motion. The marble saw is a thin plate of soft iron, without teeth, strained in a rectangular wooden frame. It does not itself cut the stone, but is the vehicle whereby the cutting is effected by means of sharp sand and water continually supplied to the plate during the sawing process. For a moderately soft marble a coarse sand is employed, but for the harder kinds a fine sand is used, such as can be obtained from road sweepings where flint is much employed. These sweepings are carefully cleansed by washing in perforated copper sieves, and all extraneous matters removed. A piece of stone or gravel accidentally getting beneath the saw would roll backwards and forwards under the edge, and thus prevent its action on the finer particles of flint, and consequently hinder the cutting of the marble. The way in which the sand and water are continuously supplied to the saws is as follows:—A barrel of water is placed near the block of marble, and a little above it. Near the bottom of this barrel is a small hole, stopped by a wooden peg; but as the withdrawal of the peg would send down too large a stream of water, a groove is cut in the peg, through which a minute streamlet issues continually. This is directed to the required spot by a slanting board, down which it trickles, but not without carrying with it a small quantity of sand, a little heap of which is placed near the path of the water, and is drawn forward in small quantities so as to mingle with the stream. The workman uses for this purpose a wooden stick, called a *drip-stick*, provided with an iron hook or an old knife blade fixed to its extremity.

The sawing of blocks or slabs of moderate size is

(1) The French artists also use thin polished plates of marble as a substitute for ivory in miniature painting. The slices of marble are cemented down upon a sheet of board paper, to prevent danger of fracture, and to hold the marble firmly, and it is not affected by heat or damp; whereas ivory becomes yellow; in hot climates is liable to split or warp; and it can only be obtained of limited size. Plates of marble 12 inches by 10, and $\frac{3}{16}$ inch thick are prepared; the smaller sizes are much thinner. These slabs can also be used for oil paintings.

effected by hand; but where large masses have to be acted upon, the operation is most effectually and economically done by machinery. The weight of the saw and frame is considerable, and supplies sufficient pressure to enable the sand to penetrate the marble; but where the work is done by hand, this pressure sometimes causes the work of pushing the saw backwards and forwards to be a very laborious one. It is therefore usual to have a counterpoise weight over the saw-frame, with a cord and pulley, so as to reduce the pressure to the required amount. This is a relief to the workman, but necessarily diminishes the cutting power of the sand. The process of sawing is, however, a subsequent one to that of marking out the block, which must be carefully done, so as to allow of the greatest number of parallel slabs being cut from it. For this purpose, the block is first shifted on rollers into the position in which it is to be sawn, and then mounted on square pieces of wood called *skids.* The lines are drawn with a soft piece of black slate called *black:* experience alone can teach the best and most economical way of doing this. All the lines are carefully examined before the sawing commences, a plumb-line being used to determine their accuracy, and this being ascertained, the top lines are chased, or cut in about $\frac{1}{8}$th of an inch deep with a narrow chisel, to form a groove for the saw and its accompaniment of sand and water. The end lines are also chased in the same way, to avoid the danger of getting the lines obliterated during the progress of the work.

The saw, Fig. 1382, is from 5 to 10 feet long, and from 4 to 5 inches wide, but its thickness is only from $\frac{1}{8}$th to $\frac{1}{6}$th of an inch. It is fastened to the upright side of the frame at each end by an

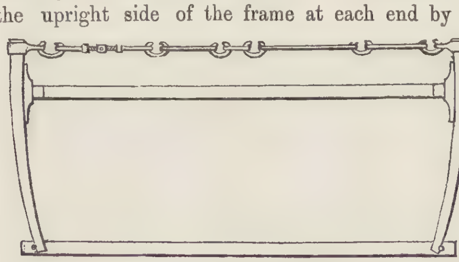


Fig. 1382.

iron pin, and is kept distended by a wooden stretcher called the *pole,* placed about a foot from the top of the frame, and resting at each end against a loose block of wood called the *bolster.* The upper ends of the frame are drawn together by a chain made of looped iron rods, and the tension is given by a double screw which has holes for a lever, and is therefore capable of being worked with great power, so as to compress the heads of the frame to the utmost, and so distend the saw. The lower end of the frame on each side serves as a handle, by which the saw is made to traverse backwards and forwards by the workmen. The depth to which the saw can penetrate in the stone is regulated by the distance apart of the blade and the pole, therefore the pole is placed at different heights from the blade according to the work in hand. All parts of the frame are capable of being detached, so that poles, saws, and *heads* (as the sides of the frame are called), can all be changed at pleasure. In commencing the work, great care is required to keep the saw perfectly upright, for if it once takes a direction oblique to the black lines previously drawn, the slab cannot fail to receive injury; for, although the saw may be speedily righted and the vertical line resumed, yet at the place where it deviated, a hollow will be produced called a *gall,* which must be rendered level with the rest of the slab, by much subsequent labour in grinding away the elevated parts. This reduces the thickness of the slab, and perhaps renders it less fit for the purpose to which it is to be applied. The saw is usually chosen about 2 feet longer than the block to be cut, and when 2 small blocks are to be divided, they are often placed end to end, and both cut through at once. If subdivisions of the slab are needed, these are cut from the larger slab on a bench with a stone or marble surface called a *rubbing-bed.* Here the lines are marked and chased on the slab, and the cutting is effected by a *grub-saw,* Fig. 1383. This is a blade of iron, not extended in a frame, but clamped at the upper edge between 2 pieces of wood. This saw

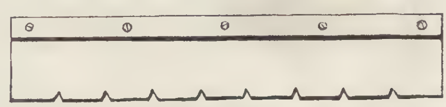


Fig. 1383.

must be shorter than the block of marble to be operated upon, because it rapidly wears away; and if the ends projected, as in the former case, the wear would be very unequal and the blade, hollowed out in the middle, would soon become useless. On the other hand, if the grub-saw is much shorter than the cut, the tendency is for it to wear rounding in its length, to counteract which, notches are sometimes filed in the blade, which are supposed to make the wear of the saw more equal, and at the same time to allow the sand and water to reach the bottom.

When the slabs have been by this means reduced to their proper dimensions, they are laid on the rubbing-bed, and ground flat by means of a smaller slab of hard stone, called a *runner.* This, with sand and water as a grinder, is worked over the entire surface of the slab, by means of a handle, which for small runners may be vertical or fixed at an angle; but for large runners must be of considerable length, and made to grasp the runner by means of an apparatus of wood, and a loose ring called a *hook.* But the runner is in some cases made of iron instead of stone, and if so, the handle is passed through holes in its projecting ends. Whether of stone or iron it is pushed backwards and forwards in all directions, working the sharp sand and water, with which it is plentifully supplied, over the surface. As the marble approaches completion, the sand is changed for finer kinds, which are gradually substituted until at last the best and finest sort, called *silver-sand,* is applied to give the last smoothing effect, preparatory to polishing, though some of the latter processes are often included under this head, and called *grounding.*

The polishing of marble is differently carried on, according to the nature of the work. For small slabs or objects of an ornamental kind, the highest degree of finish is requisite. Polishing is commenced with pumice-stone and water, and with snake-stone, after which various rollers or rubbers are employed. If the object be large and flat, the rubber may be a wooden block faced with thick woollen cloth, or a mere bundle of woollen or other rags compressed in a rectangular iron frame, and moved about with a handle. For smaller works, rollers of woollen cloth or list about 3 inches in diameter are employed. Some of these are charged with flour, emery, and a slight degree of moisture, which produces a kind of greasy polish uniformly over the surface. A similar roll of cloth, charged with putty-powder and water, completes the process. In some of the most delicate works, crocus is used intermediately between the emery and the putty-powder, but this is only with dark-coloured marbles. The marble is carefully washed after each operation, to prevent the scratching of the surface, which would result from the mixing of different particles. Some workmen give a final rubbing up of the work with coarse linen rags.

It is obvious that in the case of mouldings in marble, the methods of cutting, grinding, and polishing, must vary from the above. A pattern in card-board is taken of the exact form of the moulding about to be executed, and a counterpart is also prepared, either in sheet metal, or in wood. An outline of the moulding is then drawn on the end of the piece of marble to be operated on, and the form is roughly made out, either by chipping, or by toothed, or grub-saws. Lines are then drawn on the face of the work, the more distinctly to make out the several parts of the moulding. These parts are worked first as square fillets and small chamfers, and then rounded with small chipping chisels, according to the shape of the mould, which is constantly referred to as a pattern. The surfaces are then ready for grinding, which is effected by means of stone or iron rubbers, shaped so as to fit the several curved or square edges of the moulding, and charged with sand of various degrees of fineness. The smoothing and polishing are carried on with small slips of grit-stone, and snake-stone, followed by putty-powder, on the ends of soft deal sticks, then rubbers of worn-out felt, and finally linen rags and putty-powder.

For circular works which admit of turning the following is the method adopted by Messrs. Hall, of Derby, and described by them in the "Jury Report," already referred to:—"Having chosen a piece of marble about the size required, and free from veins, vents, &c., to which black marble is very subject, the first process is to level one face, and with a pair of compasses strike a circle round the outer edge, then with a mallet and pointed chisel, work it roughly to a circular form. It is then ready for the lathe, and being fastened with a resinous cement to an iron chuck, it is screwed to the lathe-spindle, and a very slow motion given to it. The only tool used is a bar of fine steel about 30 inches long by ¾ inch square, drawn to a point, and well tempered. This is forcibly applied to the marble, which it reduces to the proper form by slowly spelching off small pieces. After the correct outline is acquired with this tool, it is ready for the grinding process, the first being to apply a piece of coarse and hard sandstone with water, (the lathe now having a rapid motion,) until all the tool marks are ground out. A finer piece of sandstone is then used to remove the coarse scratches of the previous one, and so on with a few other and still finer stones, until all the scratches are quite obliterated. This prepares it for polishing. A piece of cotton cloth, washed quite clean, and well rubbed with flour emery is applied to the marble, and polishes it to a certain extent. A similar piece of cloth is then rubbed over with putty-powder (white oxide of tin), which gives a very high polish."

For several years past the working of marble by hand has been in great measure superseded by the use of machinery, which not only expedites the various processes, but gives greater exactness, and admits of a more economical treatment of the material. In sawing the blocks asunder, the construction of the saw already described is closely followed, but the frame is much larger and stronger, and is so arranged as to guide the action of a number of saws fixed in a vertical plane parallel to its length. Fig. 1384 will convey a general idea of the horizontal sawing-machine for marble, patented by Mr. James Tulloch in 1824, and thus described:[1]—The iron frame-work of the machine consists of 4 vertical posts strongly connected together at the top and bottom, to form a stationary frame from 10 to 14 feet long, 4 to 5 feet wide, and 8 to 12 feet high, within which the block of marble to be sawn is placed. The 2 upright posts at each end of the stationary frame have, on their insides opposite to each other, perpendicular grooves, within each pair of which slides up and down a square vertical frame: to the lower end of each of these slides is affixed a spindle, carrying 2 guide pulleys, or riggers, upon which the horizontal saw-frame rests, and is reciprocated backwards and forwards. The saw-frame is thus traversed within the fixed framing, and supported upon the 4 guide pulleys of the vertical slides, which latter are themselves suspended by chains coiled upon 2 small drums placed overhead. On the same spindle with the drums is a large wheel, to which a counterpoise weight is suspended by a chain. The weight of the counterpoise is so adjusted as to allow the saw-frame to descend when left to itself, and which thus supplies the necessary pressure for causing the penetration of the saws. The saw-frame is made rectangular, and from 2 to 3 feet longer than the distance between the vertical slides, in order to permit of the horizontal traverse of the saws, which is from 18 to 20 inches.

(1) Mr. Tulloch's machines are described in the "Repertory of Patent Inventions," for 1836: but the date of the patent is 1824 They are also described in a very clear manner in the third volume of Holtzapffel's "Mechanical Manipulation." Our figures are from the machines at the London Marble Works, Escher-street, Millbank, which, with the permission of the proprietors, we were allowed to examine and copy.

To allow of the blades being fixed in the frame with the power of separate adjustment, every blade is secured by rivets, in a clamp or buckle at each end; the one extremity of the buckle embraces the saw, the other is made as a hook; the buckle at one end of the saw is hooked upon a horizontal bar, fixed across the end of the saw-frame, and the opposite end of the frame has a groove extending its entire width, through which a separate hook, provided with a vertical tightening wedge, is inserted for every saw, which thus admits of being replaced without deranging the position of the neighbouring blades. The distances between the saws, and their parallelism with the sides of the frame, are adjusted by means of iron blocks, made of the exact thickness required in the slabs of marble, the blocks and blades are placed alternately, and every blade is separately strained by its tightening wedge until it is sufficiently tense; the blocks are sustained between 2 transverse bars, called *gage-bars,* and are allowed to remain between the blades to give them additional firmness. The traverse of the saw-frame is given by a jointed connecting rod, attached by an adjustable loop to a long vibrating pendulum, that is put in motion by a pair of connecting rods, placed one over the other, and leading from two cranks driven by the engine. All three connecting rods admit of vertical adjustment on the pendulum. The connecting rod of the saw-frame is placed intermediately between the other two, but its exact position is regulated by the height at which the saws are working, as it is suspended by a chain and counterpoise weight, which allow it to descend gradually downwards on the pendulum with the progress of the cut, so as always to keep the connecting rod nearly norizontal. Sometimes 4 of these sawing machines are grouped together, with the driving shaft and pendulums in the middle, and so arranged that each pair of frames reciprocate in opposite directions at the same time, in order to balance the weight and reduce the vibration. Various modifications in the form and arrangement of saw-frames have been from time to time adopted, but they are not of importance to the general principle.

Much difficulty was experienced in supplying mechanically to the whole of the saw-blades in these machines a simultaneous flow of sand and water, but this difficulty has now been overcome by means of an iron cistern or trough filled with water, extending across the width of the saw-frame, and having about 20 small cocks arranged along each side. From these cocks the water flows in minute but constant streams, which are received below in little boxes, and conveyed along a grooved trough filled with sand. The grooves or *tunnels* (for they are partially covered,) take a curved form, as shown in Fig. 1385, and slope downwards, by which means the equal flow of the sand and water is secured. The water flowing through the tunnels constantly undermines the sand on the convex side, which is open for its admission, and thus without the obstruction which might occur in open grooves, and without the danger of the water making for itself a channel, and leaving the sand behind, the desired object is effectually secured. Fig. 1385 represents the form of the grooves at the bottom of the sand trough.

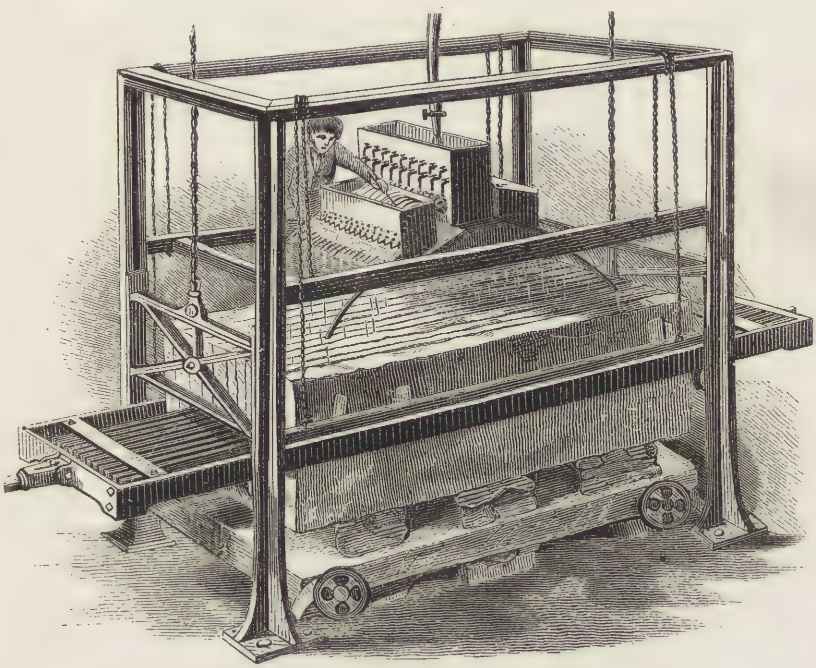


Fig. 1384. HORIZONTAL SAWING MACHINE.

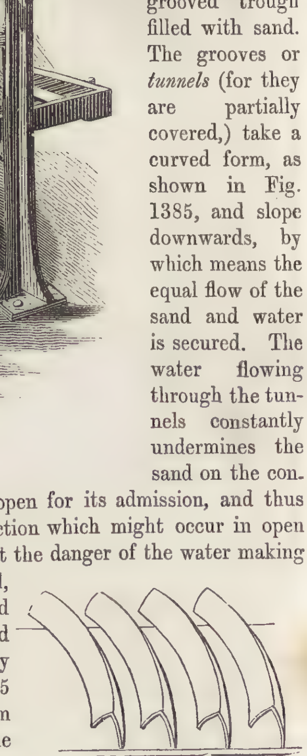


Fig. 1385.

The sawing-machines above described are set in action in the following manner:—The saw-frame is raised by means of a windlass, and the suspending chains attached to the vertical frames, and the block of marble is then wheeled into its position beneath them, and adjusted by wedges. The saws are then

lowered until they rest upon the block, the counterpoise weights are adjusted, and the mixed sand and water allowed to run upon the saw-blades, which are put in motion by attaching the connecting-rod to the pendulum. The sawing then proceeds mechanically, until the block is divided into slabs, the weight of the saw-frame and connecting-rod causing them gradually to descend with the progress of the cutting. To allow the sand and water to flow readily beneath the edges of the saw-blades, the horizontal frame is lifted slightly at the end of each stroke; for which purpose, the lower edges of the frame which bear straight upon the guide-pulleys for nearly the full length of the stroke, have a short portion at each end made as an inclined plane, which on passing over the guide-pulleys, lifts the frame just sufficiently to allow the feed to flow beneath the saws.

When the marble has been sawn into slabs, it is cut up into narrow pieces for shelves, &c., by means of circular saws, in a machine called a *ripping-bed*, Fig. 1386. It consists of a bench 12 or 14 feet long, 6 or 7 wide, and 2½ high; upon the top of the bench are two rails, upon which a platform mounted on

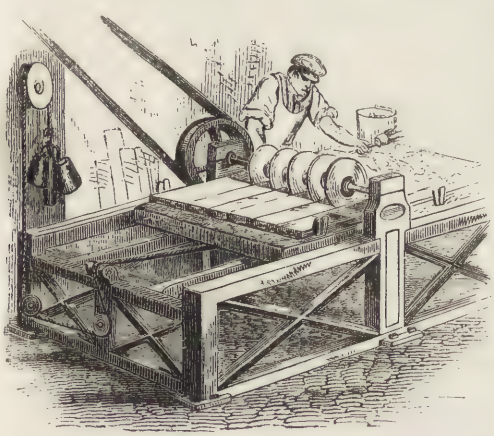


Fig. 1386. RIPPING BED.

pulleys is drawn slowly forward by a weight. The circular saws have smooth edges, and are fed with sand and water: they are mounted on a horizontal axis, which revolves about 9 inches above the platform, and to prevent the saws from turning round *upon* instead of *with* the axis, a projecting rib or feather extends the whole length of the axis. The saws are circular plates about 17 inches in diameter: they are clamped between two collars about 6 inches in diameter, fitted so as to slide upon the spindle, and be retained at any part of its length by side screws. The slab of marble is imbedded in sand upon the platform, and the edge of each saw is surrounded on one side with a small heap of moist sand. The saws are set in motion so as to cut upwards, and the platform is slowly traversed under the saws by the weight which keeps the slab of marble constantly pressing against the edges of the saws. The slab is raised to the required height for cutting it through by means of a layer of sand spread evenly over the platform, and as the saws diminish in diameter by wearing away, the layer of sand is increased in thickness. By a recent improvement, the axis of the saws is mounted in a vertical slide adjusted by a rack and pinion, by which means the saws can be raised or lowered to the exact distance required for cutting through the slab.

Circular slabs for table tops, &c., are brought into form by means of revolving cylindrical cutters. For disks of small diameter, such as those used in tesselated pavements, the cutters are made as hollow cylinders of sheet-iron of various sizes, each attached by screws to a circular disk of cast-iron, as shown in section,

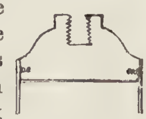


Fig. 1387.

Fig. 1387. Each cutter is screwed to the lower end of the spindle, Fig. 1388. This spindle works in cylindrical bearings, and can be elevated or depressed as required. It is suspended at the upper end by a swing collar attached to a connecting-rod jointed to the middle of a horizontal lever. The weight of the vertical rod gives the pressure required for the cutting, and the whole can be raised from the horizontal table, on which the work is adjusted, by means of a rope attached to the end of the lever passing over a pulley. Wide notches are made in the lower edge of the cutter to allow the sand and water freely to enter. For large disks, 6 feet in diameter, for example, the cutters are arranged as shown in Fig. 1389. A circular plate screws into the extremity of

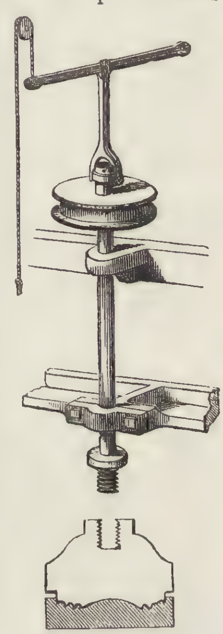


Fig. 1388.

the vertical spindle, and to this plate is bolted a wooden cross. The cutters *c c*, which are detached plates of iron of various dimensions, according to the size of the work, are each riveted to a clamp passing through a radial groove near the extremity of each arm, and retained by a wedge. Every different diameter requires a different curve in the cutters.

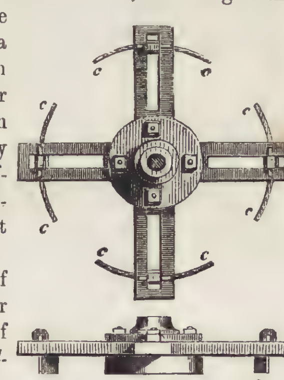


Fig. 1389.

In the grinding of works of small or moderate size, laps of cast-iron, called *sanding-plates*, are used, varying from 6 to 14 feet in diameter, and mounted upon vertical spindles. Across the face of each plate, and nearly touching it,

are fixed one or two stops, which prevent the work being carried round by the plate, and also act as a guide to ensure the work being ground square. These stops consist of strong square bars of wood faced with iron. The face to be ground is placed flat upon the lap, with the side of the piece of marble in contact with the guide-bar. Water is allowed to drip upon the plate from a cistern above, and small quantities of sand are sprinkled on it as required, and the workman exerts a certain pressure upon the work, occasionally shifting its position to prevent the formation of ridges. When two pieces of exactly similar size are to be ground on the face and edges, as for the upright sides of a chimney-piece, the two pieces of marble are cemented together back to back, with plaster of Paris (a plan called *lining*), and the pair are ground as one piece on all four faces. Some of the large grinding plates accommodate 4 to 6 men, in which case 2 or 3 guide-bars are fixed across the plate. To protect the men from the wet which is whirled off by the centrifugal force of the plate, a rim is fixed above the level of the lap, or where the work is too large to admit of this, each man stands within a kind of trough made like a box, but without any top or back.

For large slabs of marble or stone, Mr. Tulloch's *grinding-bed* may be used with advantage. In this machine, an elevation of which is shown in Fig. 1390, the slab to be ground is placed horizontally upon a moving bed, and the grinding is produced by sand and water, by means of a large flat plate of iron resting upon the surface of the slab. "The two surfaces are traversed over each other with a compound motion, partly eccentric and partly rectilinear, so as continually to change their relative positions. The machine consists of a frame about 9 feet long, 6 feet wide, and 8 feet high: about 2 feet from the ground is mounted a platform that is very slowly reciprocated horizontally for a distance of from 1 to 2 feet, according to the size of the slab, by means of a rack and pinion placed beneath and worked alternately in both directions. Above the platform are fixed, vertically, two revolving shafts, having at their upper extremities horizontal toothed wheels, of equal diameter, which are driven by means of a central toothed wheel hinged on the driving shaft. The two vertical shafts are thus made to revolve at equal velocity, or turn for turn, and to their lower ends are attached two equal cranks, placed parallel to each other, the extremities of which, therefore, describe equal circles in the same direction. To these cranks the iron grinding plate or runner is connected by pivots, fitting two sockets placed upon the central line of the plate. The cranks are made with radial grooves, so that the pivots can be fixed by wedges at any distance from the centre of the cranks. When the machine is put in motion the grinding plate is thus swung round bodily in a horizontal circle of the same diameter as the throw of the cranks, which is usually about 12 inches, and consequently every portion of the surface of the grinding plate would describe a circle upon the surface of the slab if the latter were stationary. But by the slow rectilinear movement of the platform the slab is continually shifted beneath the plate so as to place the circles, or rather the cycloids, in a different position; and it is only after many revolutions of the cranks that the same points of the surfaces of the grinding plate and slab are a second time brought in contact. The grinding plate is raised for the admission of the slab by means of 4 chains suspended from a double lever, and attached to the arms of a cross secured to the centre of the upper surface of the plate, which is thus lifted almost like a scale pan. For slabs that are much thicker or thinner than usual, the principal adjustment is obtained by the removal or addition of separate beds, or loose boards, laid upon the platform to support the slab at the proper height. Slabs that are too large to be ground over the whole surface at one operation, are shifted once or twice during the grinding." The weight of the horizontal plate supplies the pressure required for grinding; and the pressure can be regulated if necessary by a counterpoise weight attached to the double levers. The sand and water required for the grinding is thrown upon the grinding plate, which is pierced with a number of holes, and is surrounded

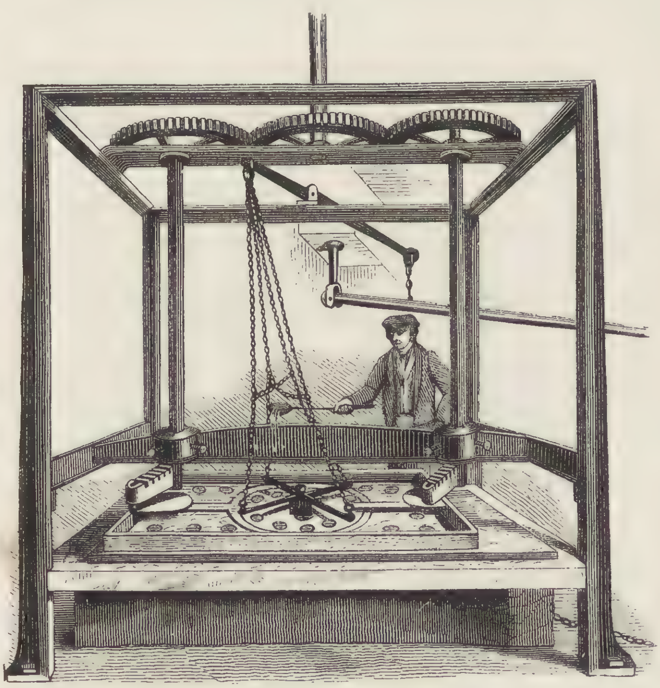


Fig. 1390. GRINDING BED.

by a ledge, so as to form a kind of shallow tray. The sand and water find their way beneath the plates through these holes, and gradually work their way out at the edge.

Straight mouldings in marble are wrought by a machine similar in construction to the ripping-bed, Fig. 1386, only instead of thin cutting disks of sheet-iron, the grinders are solid cylinders of cast-iron turned to the counterpart forms of the required mouldings.[1] The forms of some of these grinders are

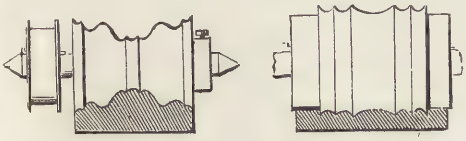


Fig. 1391.

shown in Fig. 1391, in which the outlines represent the grinders, and the shaded part the form of the moulding produced by them. Mouldings in the edges of narrow slips are sometimes produced in pairs, the two pieces being cemented together sideways as one block, which is placed edgeways on the machine. Each grinder has a central hole for the axis of the machine, and the vertical adjustment of the axis mentioned with reference to Fig. 1386, is in this machine a necessary accompaniment. Small flat circular mouldings are formed by grinders adapted to the figure required, and worked by the vertical spindle, Fig. 1388, at the bottom of which is represented a section of one of these grinders for circular work. The larger circular mouldings, such as the base of a column, are turned after the manner described by Messrs. Hall, already quoted.

Circular works are usually polished in the lathe, but rectilinear works in a polishing bed, Fig. 1392. Above the bench is fixed a crank driven by the engine: from this a connecting-rod leads to an iron swing frame, working as a pendulum, placed 2 or 3 feet from the end. The swing frame consists of two rods moving upon centres above, and carrying near their lower extremities a horizontal bar extending the entire width of the bench, and to this bar are attached as many separate iron rods as there are rubbers to be employed at one time; each rod is jointed to its own rubber, which for flat surfaces is a block of wood about 2½ feet wide, covered with thick felt, and charged with emery in the first stages, and putty-powder for finishing. The rubbers are shifted across the width of the slab by sliding them to another position on the horizontal bar of the pendulum frame, and the platform of the machine is traversed endways by a chain and drum, or a rack and pinion, so as to expose the work equally to the action of the rubbers. For rectilinear mouldings elastic rubbers are used: they are made of coarse cloth, such as old sugar-bags cut into strips about 6 inches wide, folded lengthways, and nailed through the middle of the fold close together to a block of wood, so as to present a surface 8 or 9 inches wide, composed of the edges of the cloth, which penetrate into the angles of the mouldings.

Various other patents have been taken out for improvements in machinery for cutting marble and stone, one or two of which may be noticed. And, first, with respect to the usual method of cutting marble with the saw, Fig. 1382. The heavy construction

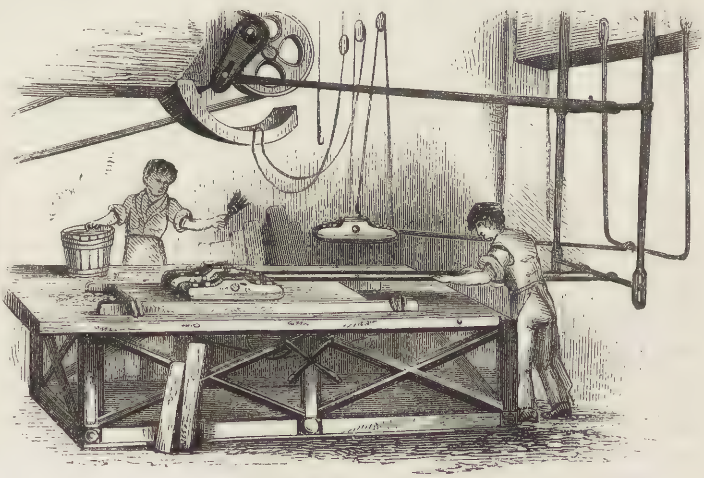


Fig. 1392. POLISHING BED.

of this saw renders the work very laborious, and much skill and judgment are required to drive it upright and true. According to Mr. Hutchison, marble cut by steam power produces so rough a surface, that what is gained in speed and labour is counterbalanced by the labour required for *closing* the surfaces for the polisher: extra capital is also required for keeping an assorted stock of marble slabs of all dimensions and thickness. "Stone is hardly ever cut or sawed by steam power, as it is generally used in more solid substances than marble; and also on account of the probability of the saws coming in contact with flints, through which the saws could not cut; and hard coloured marbles are also cut by the old method of hand-sawing, owing to shells and other hard matter found therein. Good statuary marble is, I believe,

(1) The methods of cutting in the ripping-bed and grinding by means of solid cylinders, form the subject of Mr. G. W. Wilde's patent, sealed 15th April, 1833. This patent is declared to be "for the sawing of marble or other stone by means of a revolving circular metallic plate, smooth or not serrated on the face or edge, and applied with sand and water as is done with the straight saw; and also for making on the surface or periphery of a metallic or wooden cylinder or wheel, the converse of the intended moulding or grooving, by means of which a series of mouldings or grooves can be wrought on a surface of marble or stone at one operation with sand and water, and in like manner polished with putty, buff, or pumice-stone, or other polishing material." In 1822, Sir James Jelf patented a combination of machinery for cutting parallel mouldings upon marble slabs. Brown's machinery is of still older date.

never cut by steam-power, as the vibrating movement stuns and renders the surfaces of the slabs coarse." Mr. Hutchison in 1843 patented an invention which he calls a saw-guide, which is said to produce better work, and to enable any labourer or strong youth to drive one or more saws with ease. Fig. 1393 is an elevation, and Fig. 1394 a plan of the saw as mounted for work. A is the frame-work, B the roof or covering, C the saw-guide, which admits of being

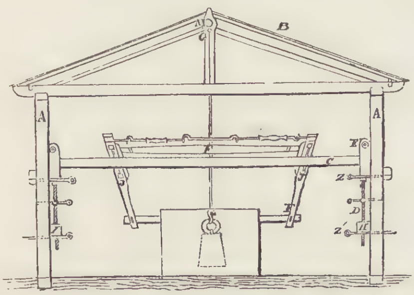


Fig. 1393.

raised or lowered by screws D, and also adjusted laterally by screws E. The saw-guide rests upon, and is guided by the cross-rails X resting upon the movable pins Z. F is the frame-saw of the usual construction for hand-sawing; and in being moved backwards and forwards it is guided by the saw-guide C.

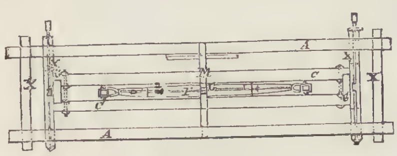


Fig. 1394.

G is a movable pulley with a suspended weight to relieve the heaviness of the saw or saws and tackle, to allow the sand to run under the saw-plates, each pulley being attached to a ring which slides freely on the bar M above. H and I are movable rails of wood resting on iron pins Z′; these rails have holes to allow vertical screws, D, to work through; they raise or lower the saw-guide C. J J are friction rollers to the saw-frame, to facilitate its movement between the saw guide.

In 1843 Mr. C. J. Wollaston took out a patent for improvements in machinery for cutting marble and stone, which we notice for the sake of describing his method of cutting pipes or tubes of that material. Fig. 1395 shows a front view of the machine, and Fig. 1397 a side elevation partly in section, Fig. 1396 two plans thereof. A A are two pillars which act as guides to the plates B C, which are combined together by means of screws D D and nuts F F. On the plate B is placed the block of stone or marble to be cut, and E is a plate brought to press on the upper end of the block to keep it in its place. The frame consisting of the plates B C, and screws D is suspended from the cross-head or top plate G, by means of the screw H, and this screw is made to descend by the action of the cog-wheel I, which turns in a suitable bearing in the cross-head or top plate, and a hollow screw is formed through the nave of the wheel to fit the screw H: hence by turning the wheel I, the frame with the stone or marble descends: motion is given to the wheel I, by means of the pinion J, affixed on the shaft K: the pinion J takes into and drives the cog-wheel 1, which moves on the axis 2, and to the wheel 1 is affixed the pinion 3, which takes into and drives the cog-wheel I; the shaft K receiving

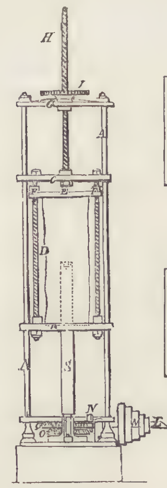


Fig. 1395.

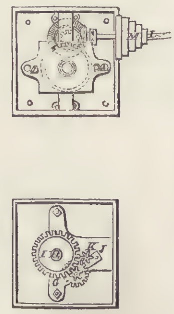


Fig. 1396.

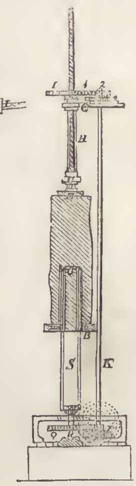


Fig. 1397.

motion from the driving shaft L in the following manner: M is a series of pulleys to receive a strap from a steam-engine or other power; on the shaft L is affixed the bevelled toothed wheel N, which takes into and drives the bevelled tooth wheel O, affixed to the shaft K; and on the shaft K is affixed the pinion P, which takes into and drives the cog-wheel Q affixed to the axis R, which carries the cutter tube S, which tube is affixed to the axis and turns therewith. On the upper end of the tube are attached a series of cutters, and as these revolve with the tube, the stone or marble is cut, and as it is cut it is lowered; the inner part cut out descending into the tube, will serve, if desired, for making another tube in a similar manner.

MARBLES are made in large quantities for boys. Some of them are formed of potter's clay, glazed and burnt in a furnace; others are made of marble and alabaster, but the greater number are of a hard calcareous stone, which in Saxony is prepared in the following manner:—The stone is broken into square blocks with a hammer, and rounded into spheres by a mill; for which purpose they are placed 100 or 150 at a time upon a fixed slab of stone containing a number of concentric grooves or furrows. Above this stone a flat slab or block of oak of the same diameter, supported by a lever, is turned round by the power of the mill, and while in motion small threads of water are made to enter each of the concentric grooves, whereby the wood is prevented from heating and the balls are rounded and polished. In about 15 minutes the marbles are finished and are fit for sale. Immense quantities are exported to India and China. A mill

with 3 turning blocks will manufacture 60,000 marbles per week.[1]

MARBLING is a very curious art, by means of which the edges of books and the surface of paper are covered with various peculiar devices. This subject has almost entirely escaped the notice of writers on the useful arts. An account of it as practised in Paris, was published in the year 1828, in the *Dictionnaire Technologique*, and translated into Gill's *Technological Repository* about the same time. We will first give an abstract of that paper, and then state the details of the art as witnessed by the Editor.

The colours are arranged by a peculiar sort of brush upon the surface of a solution of gum, and the sheet of paper or book edges is placed upon this in such a way as to cause the adhesion of the colour without disturbing the pattern. When the sheet has been dried it is waxed and glazed. The finishing of the edges of books is generally left to the bookbinder.

The solution of gum forming what is called the *couch* or *bed* is prepared by adding 3 ounces of gum tragacanth to half a pailful of water, and stirring it frequently during 6 days. This solution will serve for marbling the edges of 400 volumes. A much stronger solution of gum is also made in order to increase the thickness of the couch when required.

Some hours or at most the day before the marbling, a quantity of ox-gall is beaten up with its own weight of water, and a solution of camphorated spirit (formed by dissolving 18 grammes[2] of camphor in 25 grammes of alcohol) added thereto, beaten up thoroughly, and the whole filtered.

The wax is prepared in the following manner: yellow virgin wax is to be melted in a glazed earthen vessel over a slow fire: when thoroughly melted it is removed from the fire and a quantity of turpentine stirred in until it is of the consistence of honey. A drop of the mixture is put upon the thumb nail from time to time and allowed to cool, and in this way the proper consistence is judged of.

The colours employed are the ochres and such animal and vegetable matters as will float upon the gummed surface. Naples yellow, or the yellow lake from weld, supplies *yellow*. *Golden-yellow* is made with terra de Sienna unburnt. Indigo supplies *blues;* carmine, or carmine lake, *red;* umber is used for *brown;* ivory black for black; *white* is produced by the gall; *green* from a mixture of blue and yellow; *violet* from yellow and red. The colours must be ground very fine with a muller upon a porphyry or marble slab, with the prepared wax and water, and a few drops of alcohol. When well ground a small portion of the colour is taken up with a palette-knife and allowed to fall upon the surface of the gummed water. If of the proper consistency, the colour is collected into an earthen pot for use.

The solution of gum is prepared for the marbling vat in the following manner:—200 grammes of alum in fine powder are added to as much of the prepared gum as will cover the bottom to the depth of an inch, and well beaten up until dissolved. A spoonful or two of this solution is poured into a small conical vessel and a drop of the colour allowed to fall upon the surface, when it is to be distributed in a circular form by means of a small rod. If it extend well and form a good spiral figure without dissolving in the gum, the solution is sufficiently strong; but if the colour will not turn, the gummed water is too thick, and water must be well beaten up with it: if, on the other hand, the colour spread too much and dissolve in the gummed water, then some of the stronger prepared gum must be added. When, by repeated trials, the gum water is found to be of the proper consistence, it is to be passed through a sieve into the marbling vat, so as to form a stratum at the bottom to the depth of one inch. The colours, too, being ground and thickened with the prepared wax and ox-gall so as to be of the proper consistence for working, a quantity of gall is first spread over the surface of the gummed water. The thinnest colour that is to be used is then thrown on; then a colour which is somewhat thicker; then a third thicker still, and so on, the thicker colour pressing upon the thinner immediately below it and causing it to spread. When all the colours are thrown on, the pattern is worked out: if a volute or spiral be required, a rod is held upright in the hand of the operator and carried along amongst the colours in a spiral course. The colours are thrown on with a kind of pencil or small broom, prepared as follows:—twigs of osier about a foot long and two lines thick are used for the handles, and along the smaller end of the twig are tied with packthread, for each pencil, about 100 hog's bristles of the greatest possible length. With these pencils the operator throws on here and there over the gummed surface the first colour; then in the midst of that the second; then the third, and so on; so that when the colours spread, the different sets approach each other: the pattern is then formed with the stick in the operator's hand. For example, suppose it were required to produce the pattern known as *the partridge's eye;* the operator prepares two tints of blue with indigo, which we will name No. 1 and No. 2, the latter containing a larger portion of the prepared gall than No. 1. He first throws on carmine lake; secondly, the terra de Sienna; thirdly, the indigo No. 1; and fourthly, the indigo No. 2; he next jerks on two drops of turpentine. The blue, No. 2, last laid on extends all the other colours and affords a clear blue in spots, an effect which is due to the action of the turpentine upon the colours last thrown on. The marbler then takes 8 or 10 volumes, and commences by marbling their front edges, which he first prepares by laying the back of each volume upon a table, turning back the boards, and applying a clamp, which he attaches by screwing its jaws close, and thus levels the front edges, which are marbled by being plunged into the vat. Having marbled the front edges of the 8 or 10 volumes, he

(1) Archives des Découv. et Invent. 1826, quoted in Gill's Technological Repository, 1828.

(2) The gramme is equal to 15·44 grains.

loosens the clamps, and strikes up the ends so as to make them all enter the gummed water at the same level: he clamps them again and dips them as before.

The marbler can vary his patterns to any extent; they depend upon his taste in arranging the colours, and upon the number of colours employed.

Paper is marbled in a similar manner to the edges of books, but, instead of using a round staff, combs are employed, the teeth of which are more or less apart, to form the volutes or any other figure. It requires skill to place the sheet of paper flat upon the surface of the gummed water, and to withdraw it without deranging the colours. To do this, the marbler takes the sheet between the thumb and fore-finger of one hand in the middle of one of its ends, and with the other hand, and between the thumb and fore-finger also, the middle of the other end of the sheet. He then lays the sheet upon the gummed water, and removes it without suffering it to slide upon the coloured surface. He then hangs the sheet to dry upon the bar of a frame with the coloured side outwards. Fresh colours are added to the gummed surface after every dipping.

This account does not agree in many particulars with the process, as we have just seen it practised by one of the most skilful marblers in London.

The patterns are arranged into five classes, in each of which there are numerous varieties. The *first*, known as *small brown*, consists of small round spots or shells: the second is the *Spanish* pattern, consisting of a shaded ground with marble veining upon it. Patterns in these two classes are formed by simply dropping the proper colours upon the surface of the gum solution in the right order, when they arrange themselves into the required pattern. In the *third* class are *curled* patterns; the colours having been thrown on, the spiral or curl is produced by a stick: in the *fourth* class are *Dutch* patterns, in which first the stick and then the comb produce the peculiar effects. The *fifth* class includes *Gloucester* patterns, in which a wavy appearance is produced below the spots.

The trough is made of wood about 3 feet long by 2 wide, and 3 inches deep, and is placed before the window. The colours are in jars 20 or 30 in number, on the right hand side of the operator, each jar containing its own brush, which is a loose bristle-tool. Now suppose a black and white marble pattern to be required: the marbler first cleans the surface of the trough by passing a straight-edge along it, and turning the impurities over the end into a small waste trough at the side. Then taking the brush out of the black colour jar, and shaking it in the jar to get rid of superfluous colour, he holds the brush at an angle about a foot and a half or two feet over the surface of gum solution, and jerks down upon it a succession of drops, moving his hand along so as to distribute them evenly: the drops remain in the place in which they fall, and expand into disks. Returning the black brush to its jar, he next takes the white brush and lets fall a few showers of white drops. The white colour, instead of forming drops as the black did, threads its way with great rapidity among the spaces left between the black drops, producing the peculiar spotted and veined appearance of black and white marble. Then taking a sheet of paper, the operator places it flat down upon the surface, tapping it gently here and there to secure perfect adhesion: he next places a stick, about four feet long, across the longer dimension of the trough, and taking up the paper by its two further corners, turns one half of the sheet over the stick: then lifts the stick off with the paper hanging upon it marbled in the most perfect manner. In fact, wherever the prepared liquid surface is touched by the paper, the whole of the pattern is completely transferred from the liquid to the paper. The stick is then placed across a space between two horizontal bars and left to dry The trough is dressed as before, for the marbling of a second sheet in a similar manner.

Now in this operation it is evident that the black colour is ground up with a liquid vehicle or menstruum different from that used for the white, so that the two colours may mingle without mixing or blending together. If one colour be mixed up with water or gall or thin gum solution, the other colour must be mixed with an oil of some kind. This will explain how it is that the colours are kept separate when only 2 are employed, but it is difficult to understand the operation when 5 or 6 distinct colours are used, each bearing its share in the general effect, just as the differently coloured threads do in a woven pattern. The marbler produced before us, with 5 or 6 colours and some curious manipulation, a pattern which he named the *Battle of Waterloo*, from some fanciful resemblance in the pattern to the colours of the uniforms of the opposing forces at the battle. After 6 successive showers of different colours, the marbler took a stick, passed it down apparently to the bottom of the trough, and then moved it rather quickly backwards and forwards in lines parallel to the shorter sides of the trough: the effect of this was to produce a streamy, wavy appearance. He next took a comb of the width of the trough, with brass teeth about $\frac{1}{8}$th inch apart, and dipping it into the trough at the left-hand extremity, moved it through the pattern, supporting the two ends of the comb on the two long ridges of the trough. All the colours streamed through the teeth of the comb, and the pattern formed by the previous operation was immediately changed into that small curious shelled effect, which is more easily conceived than described. This pattern was taken up by the paper as before. We also saw a dozen books marbled at the edges: no clamp was used except the pressure of the operator's fingers, and the concave of the upright edges was not disturbed. A book was sent to show the pattern, which was reproduced in less than a minute, one dressing being sufficient, as the edges were successively dipped into different parts of the trough.

The effects produced by this art are of a very pleasing and surprising kind. The complexity of many of the patterns is only apparent, for the patterns themselves are produced by the simple means which

we have attempted to describe. We must apologise for not giving more precise details respecting the mixing of the colours: they were purposely withheld from us, but there is no doubt that any one interested in taking up and extending and improving this remarkable art, would with a little chemical knowledge become a skilful marbler.

We may add that the English marbler professes to use the following pigments, &c. for his colours:—For *blue*, indigo, ground up with white lead or Prussian blue and verditer, may be used: for *green*, indigo and orpiment, the one ground and the other tempered, mixed and boiled together with water; or verdigris, a mixture of Dutch pink, and Prussian blue or verditer, in different proportions: for *yellow*, orpiment, bruised and tempered; or Dutch pink and yellow ochre: for *red*, the finest lake, ground with raspings of Brazil-wood, prepared by boiling for half a day; or carmine, rose-pink, vermilion, and red-lead; the two latter should be mixed with rose-pink or lake, to bring them to a softer cast: for *orange*, orange-lake, or a mixture of vermilion or red-lead with Dutch pink: for *purple*, rose-pink and Prussian blue. Into all these colours, properly ground with spirit of wine, a little ox or fish gall is added; the gall to be 2 or 3 days old: and if the colours do not dilate sufficiently, more gall is added; but if they spread too much, more colour, without the gall, is added.

The beautiful polish of marble paper is imparted by first rubbing the paper, when dry, with a little soap, and then polishing with a marble stone, an ivory knob or glass polisher, or with a jasper or agate burnisher.

MARGARIC ACID. The fatty acids are noticed in the article CANDLE, vol. i. p. 287.

MARINE ACID. See HYDROCHLORIC ACID—SALT.

MARINE SALT. See SALT.

MARINER'S COMPASS. See COMPASS—MAGNETISM.

MARL is a mixture, compact or pulverulent, of carbonate of lime, clay, and siliceous sand, and, according as one or other predominates, a marl is said to be *calcareous*, *clayey*, or *sandy*.

MARQUETRY. The nature and method of this beautiful description of inlaying are noticed under BUHL-WORK. In the marquetry or marqueterie-inlay, *woods* are arranged in a great variety of tints in the form of birds, flowers, ornaments, &c.: in buhl-work, metals are inlaid upon grounds of tortoiseshell or ebony, or *vice versâ*. The earlier specimens of marquetry were executed in woods of the natural hues, but in later times stained woods were employed; these have the disadvantage of fading by age; but in the admirable specimens sent to the Great Exhibition by M. Cremer of Paris, the woods are stained by the process of M. Boucherie, which is said to give them a permanent dye to a considerable depth. The effect of shading is produced by immersing the pieces in hot sand. The various parts being cut out of the required tints of the proper form, are placed according to the design and fixed on paper; they are then applied like veneer to the piece of furniture, after which they are cleaned off, slightly polished, and the finer lines engraved. In the manufacture of *parqueterie* for floors, the same principle is carried out as in marqueterie, only on a bolder scale. Woods of different colours are cut to pattern, and inlaid or so arranged as to produce very beautiful effects for floors.

MASONRY,[1] is the art of shaping and uniting stones for the various purposes of building. It includes the hewing of stones into the various forms required, and the union of them by level, perpendicular, or other joints; or by the aid of cement, or of iron, lead, &c. The operations of masonry require much practical dexterity, together with a certain amount of knowledge in geometry and mechanics. For the scientific operations of stone-cutting, we must refer to special treatises,[2] our object in the present article being to notice a few of the practical details of masonry.

Probably the earliest masonry is that of the *Egyptians*, which is chiefly remarkable for the enormous size of the stones employed: they are said to be often as much as 30 feet in length: they were used without mortar, for having been once placed, they were not likely to be disturbed. The *Cyclopæan* masonry alluded to by Homer, some remains of which exist in the walls at Mycenæ and Tiryns, are formed of large and irregularly-shaped masses of stone, with the interstices filled with smaller pieces. *Tyrrhenian*, or *Etruscan* masonry, is also of large and irregularly-shaped masses of stone, but they are fitted together with such exactness as not to admit of smaller stones in the interstices: the more ancient remains of Greece and Italy afford specimens of this kind of masonry. The next improvement seems to have consisted in

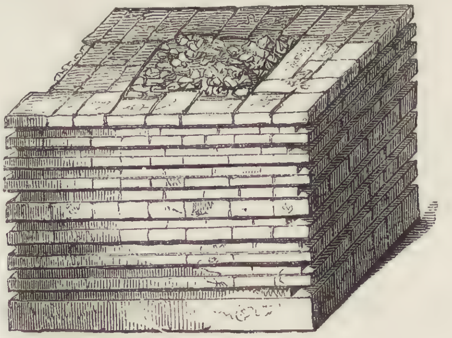


Fig. 1398. INCERTUM.

working the stones so as to make the joints or beds horizontal or nearly so, and the vertical joints were made flat, but not perpendicular to the horizontal ones: specimens of this kind of masonry are found at Fiesole, Populonia, and elsewhere. All these

(1) The derivation of the word *mason* has led to some dispute. Some derive it from the Latin *maceria*, a long wall; others from *machinæ*, because the builders used *machines* in building the walls. It appears to be the same word as *maison*, a house or *mansion*.

(2) See Peter Nicholson's "Popular and Practical Treatise on Masonry and Stone Cutting," published in 1827. Gwilt's Encyclopædia of Architecture, 1842, or the article Masonry in Rees's Cyclopædia. Also Dobson's Practical Treatise on Stone Cutting, published in Weale's Rudimentary Series.

kinds of walling were put together without mortar. For the ordinary purposes of walling, the Greeks and Romans used several methods, such as the *opus incertum*, now called *random*, or *rubble* walling and made with stones of irregular shapes and sizes: the

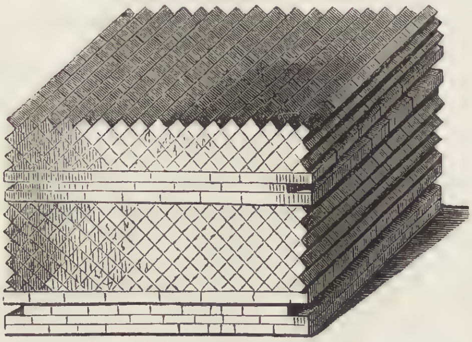


Fig. 1399. RETICULATED.

opus reticulatum, so called from its netlike appearance, formed with square stones laid diagonally: *isodomum* and *pseudisodomum*, ascribed by Vitruvius to the Greeks: they were formed in regular courses,

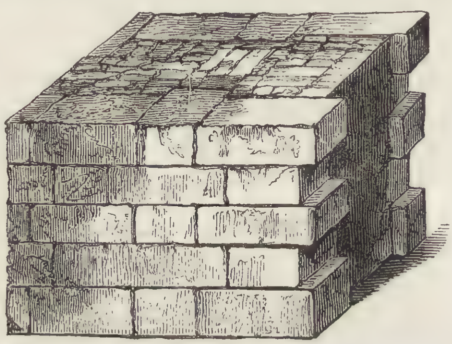


Fig. 1400. ISODOMUM.

which in the isodomum were all of equal height, but unequal in the pseudisodomum. *Emplectum* resembled the last two in external appearance, but the middle of the wall was of rubble, the facing only being in

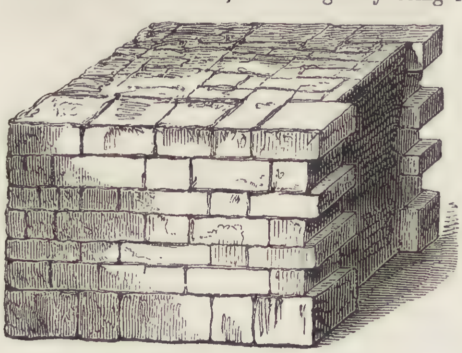


Fig. 1401. PSEUDISODOMUM.

regular courses. In all these kinds of masonry the stones were small, and were laid in mortar; but in the erection of buildings, where large blocks of stone were employed, the Romans used no cement. According to Pocock, on the west side of the basement of the great temple at Baalbec, even the second course is formed of stones from 29 to 37 feet long, and about 9 feet thick: under this at the north-west angle and about 20 feet from the ground are 3 stones, which measure 182 feet 9 inches in length, by about 12 feet

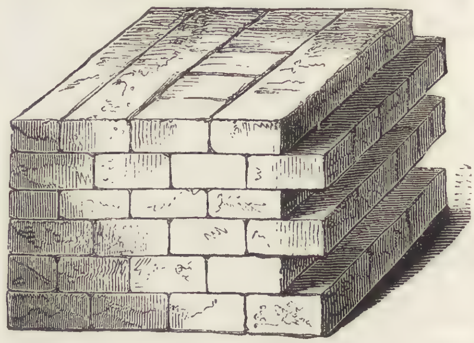


Fig. 1402. GREEK EMPLECTUM.

thick; two are 60 feet, and the third 62 feet 9 inches in length. The Roman emplectum found in England and France has in some cases courses of tiles built in at intervals, as shown in Fig. 1404, the large surfaces

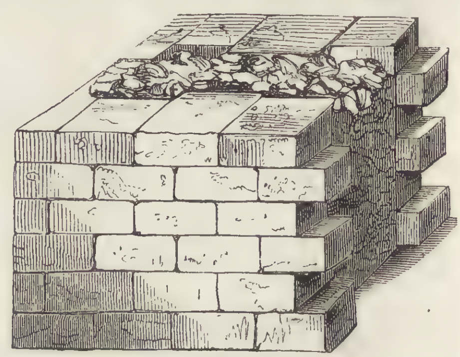


Fig. 1403. ROMAN EMPLECTUM.

of the flat tiles making a good bond. The courses are usually about 4 inches deep, the stones in most instances of rather cubical proportions, and the joints commonly wide and coarse. In forming foundations, it was common among the Romans to dig a trench, not very deep, and scarcely wider than the wall to be raised from it; the bottom of the trench was then covered with gravel or dry hard rubbish; upon this solid masonry, usually of the same width as the upper part of the wall, was built up to the level of the surface of the ground.

Fig. 1404. MASONRY AND TILES.

After the Romans had quitted Britain, the masonry probably consisted of the coarsest rag or rubble work. In a few of the early buildings, considered by some to be Saxon,

the quoins, the jambs of doors and windows, and occasionally some other parts which are built of hewn stone, are formed of blocks alternately laid flat and set up on their ends: the upright stones

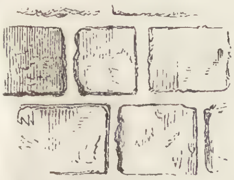


Fig. 1405. WIDE JOINTS.

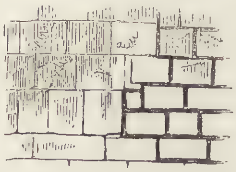


Fig. 1406. FINE AND WIDE JOINTS.

are usually of considerable length in proportion to the others; hence the term *long and short work* applied to this construction. In the early Norman style walls were built on the inside face with rubble plastered, and the outside was also often the same: in large buildings this was frequently of ashlar, with wide coarse joints, and the mortar made with coarse unsifted sand or gravel. In the early part of the twelfth century, the character of the masonry im-

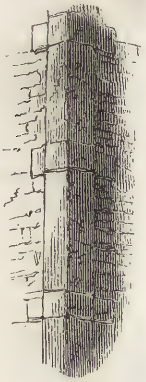


Fig. 1407.

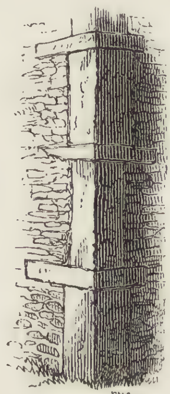


Fig. 1408.

LONG AND SHORT WORK.

proved; the mortar was finer, the stones were set with close fine joints, ashlar was more generally used for the external, and in some cases for the internal facing. Throughout the Norman style the stones of the plain ashlar work generally approached to cubes in shape, and the courses varied from about 6 to 9 or 10 inches in height; in rubble walls, *herringbone work* was frequently used. In late Norman works,

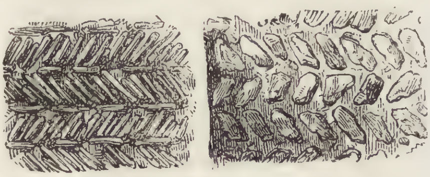


Fig. 1409. HERRING-BONE WORK.

the stones used in the facing of walls were cut into various shapes for the sake of ornament, the simplest being the opus reticulatum or diamond work, in which the stones were reduced to squares, and laid angularly. In middle age masonry the stones were seldom larger than could be lifted by two or three men, and they were often small enough to be lifted by one man. "After the expiration of the Norman style, masonry had no characteristics sufficiently decided to mark its date, except where flints were used; in rubble work these were employed in every age in districts in which they abound, but they do not appear to have been laid with any care, previously to the introduction of the Early English style. At this period they began to be split or broken to a moderately flat surface on one side, which was placed outwards, and formed a tolerably even face to the wall; but in most buildings of this date, a portion only of the flints have been thus broken, and the surface of the wall has been covered with plaster. In the Decorated and Perpendicular styles, especially the latter, flints were dressed with much greater care, and not unfrequently reduced to rectangular forms, so as to be laid in even courses with as much regularity as bricks. It was by no means uncommon for flint and stone work to be used together in walls for the sake of ornament: the most usual arrangement was in alternate squares, but sometimes the stone was cut into the shape of panelling, with tracery and cusps, and the interstices were filled with flints." [1]

Various kinds of masonry are still practised, but they all admit of being classed under three heads :—

Fig. 1410.

Fig. 1411.

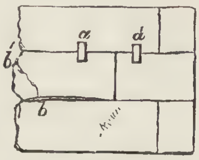


Fig. 1412.

1st. *Rubble work*, Fig. 1410, in which the stones are used without being squared. 2d. *Coursed work*, Fig. 1411, in which the stones are squared more or less, sorted into sizes, and ranged in courses. 3d. *Ashlar work*, Fig. 1412, in which each stone is squared and dressed to given dimensions. In London the term ashlar is commonly applied to a thin facing of stone placed in front of brickwork. [See ASHLAR.]

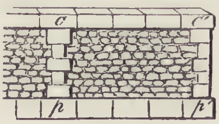


Fig. 1413.

The rubble wall, Fig. 1413, is improved in appearance and solidity by the introduction of cut stone as in the coping *c*, the plinth *p*, the quoin *c' p'*, and the piers *c p*. The wall, Fig. 1414, is cased on both sides with cut

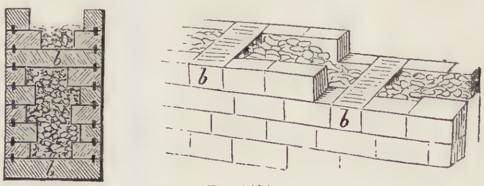


Fig. 1414.

(1) "A Glossary of Terms used in Grecian, Roman, Italian and Gothic Architecture." Fifth Edition, Oxford, 1850. These very beautiful and valuable volumes contain pictorial examples of the specimens of work and style as they actually exist.

stone, the middle being filled with rubble. In such case *heading* or *bond* stones *b b*, are carried entirely through the thickness of the wall at certain intervals, to prevent the sides being forced apart by the settlement of the rubble between them. These few explanations will enable the reader the better to appreciate the following directions, which are abridged from the article MASONRY in Rees's Cyclopædia.

In the modern practice of stone walling the bedding joints should always be horizontal, when the top of the wall is to be terminated horizontally. In bridge building and in the masonry of fence walls upon inclined surfaces, the bedding joints may follow the general direction of the work. The footing of stone walls should be constructed with stones as large as can be conveniently procured, squared and of equal thickness in the same course, with the broadest bed downwards. The vertical joints of an upper course must *break joint*, that is, must not fall on those below. If the walls of the superstructure be thin, the stones composing the foundations may be disposed so that their length may reach across each course from one side of the wall to the other. Where the walls are thick and stones cannot be procured long enough to reach across the foundations, every second stone in the course may be a whole stone in breadth, and each interval may consist of two stones of equal breadth, that is, placing *header* and *stretcher*[1] alternately. If those stones cannot be procured, a header and stretcher must be laid alternately from one side of the wall, and from the other side another series of stones in the same manner, so that the length of each header may be two-thirds, and the breadth of each stretcher one-third of the breadth of the wall, and so that the back of each header may come in contact with the back of an opposite stretcher, and the side of that header may come in contact with the side of the header adjoining the said stretcher. In foundations of some breadth, for which stones cannot be procured of a length equal to two-thirds the breadth of the foundation, the work should be built so that the upright joints of any course may fall on the middle of the length of the stones in the course below, and so that the back of each stone in any course may fall on the solid of a stone or stones in the lower course. The foundation should consist of several courses, each decreasing in breadth as they rise by sets off on each side of 3 or 4 inches in ordinary cases. The number of courses is regulated by the weight of the wall, and by the size of the stones composing these foundations or footings.

Fig. 1415 represents that form of masonry called by the Greeks *diatonous*, in which the stones were of the same form and dimensions, but placed in courses of unequal height. Such stones had their length equal to double their width.

There is a variety of masonry met with in Italy in which, instead of presenting in the same course one header and one stretcher alternating, there is a course of headers and a course of stretchers, like the old English bond in brickwork: as the headers pass

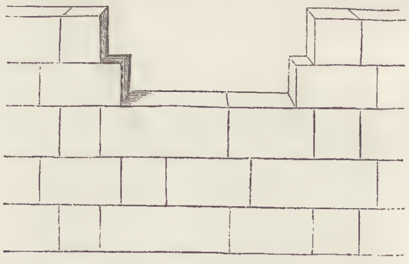


Fig. 1415. DIATONOUS.

entirely through the wall, the work is very solid. See Fig. 1416.

A wall built with unhewn stone is called a *rubble*-wall, whether mortar be used or not. This species of

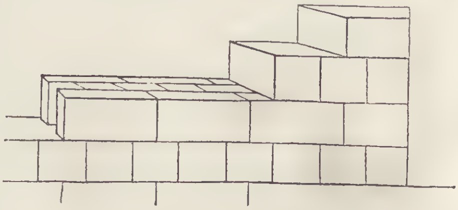


Fig. 1416. ITALIAN.

work may be *coursed* or *uncoursed*. In the former the stones are gaged and dressed by the hammer, and thrown into different heaps, each heap containing stones of the same thickness. The masonry is then laid in horizontal courses, but not always of the same thickness. The uncoursed rubble wall is formed by laying the stones in the wall as they come to hand, without gaging or sorting, only the sharp angles are first knocked off with the thick end of the scabbling hammer.

Walls are most commonly built with an ashlar facing, and backed with brick or rubble work. In London, where stone is expensive, the backing is generally of brickwork; but such is not the case in the north and in places where stone is abundant. Walls faced with ashlar and backed with brick or uncoursed rubble, are liable to become convex on the outside from the greater number of joints, and consequently from the larger quantity of mortar placed in each joint, as the shrinking of the mortar is in proportion to the quantity: such a wall is therefore inferior to one wherein the facing and backing are of the same kind, and built with equal care, even supposing both sides to be of uncoursed rubble, which is the worst description of walling. Where a wall consists of an ashlar facing outside, and the inside of coursed rubble, the courses at the back should be as high as possible, and the beds should contain very little mortar. Course rubble and brick backings admit of the introduction of bond timber; but wooden bonds should not be continued in length; and unless used sparingly they weaken the masonry, making the wall liable to bend. It is better to introduce only such small pieces, with the fibres of the wood perpen-

(1) These terms are explained in the article BRICKLAYING, to which we must also refer for directions respecting the preparation of foundations.

dicular to the face of the wall, as are required for the fastenings of battens and dressings.

In ashlar facing the stones usually rise from 28 to 30 inches in length, 12 inches in height, and 8 or 9 inches in thickness. Although the upper and lower beds of an ashlar, as well as the vertical joints, should be at right angles to the face of the stone, and the face, bed and vertical joints at right angles to the beds in an ashlar facing; yet when the stones run nearly of the same thickness, it is of some advantage, in respect of bond, that the back of the stone be inclined to the face, and that all the backs, thus inclined, should run in the same direction; since a small degree of lap is thus obtained in the setting of the next course: whereas if the backs are parallel to the front, no lap can take place when the stones run of an equal depth in the thickness of the wall. It is also of advantage to select the stones, so that a thicker one and a thinner one follow each other alternately. The disposition of the stones in the next superior course should follow the same order as in the inferior course, and every vertical joint should fall as nearly as possible in the middle of the stone below.

In every course of ashlar facing, in which the backing is brick or rubble, *bond* or *throughstones* should be introduced, their number being proportioned to the length of the course; and every one of these stones, if a superior course, should fall in the middle between every two like stones in the course below. In some cases masons introduce bond stones of greater length than the wall will allow, in order to show that they have done their work properly; but as the projecting ends have to be knocked or cut off, the wall is thus liable to be shaken, or the bond stone itself split.

In piers where the jambs are coursed with ashlar in front, every alternate jamb stone should go through the wall with its beds perfectly level. If the jamb stones are of one entire height, as is often the case when architraves are wrought upon them and also upon the lintel crowning them, every alternate stone of the stones at the ends of the courses of the pier which are to adjoin the architrave jamb, should be a bond stone; and if the piers be very narrow between the apertures, no other bond stones will be necessary in such short courses. With wide piers the number of bond stones must be proportioned to the space. Bond stones must also be carefully attended to in long courses above and below windows. Their sides must be parallel and perpendicular to each other, and their horizontal dimension in the face of the work not less than the vertical one. The vertical joints, after receding about $\frac{3}{4}$ths of an inch from the face of the work with a close joint, should widen gradually to the back so as to form hollow wedge-like figures for the reception of mortar and packing. The adjoining stones should have their beds and vertical joints filled with oil-putty from the face to about $\frac{3}{4}$ths of an inch inwards, and the running part of the beds with good mortar. Putty cement is very durable, and although the oil, spreading over the surface of the contiguous stones, produces a disagreeable effect, yet this disappears in a year or two, and the work appears as if of one piece.

All the stones of an ashlar facing should be laid on their natural beds: unless this be attended to, the stones are apt to flush at the joints, and this promotes decay from the action of the atmosphere. Where walls, or insulated pillars of small dimensions, are to be carried up, every stone should be carefully bedded level, and not be concave in the middle: for if such be the case, the weight borne by the pier or pillar will probably cause the joints to flush. The unsightly cracks seen in masonry, as at *b b′*, Fig. 1412, are produced in consequence of the stones not lying flat in their beds. It is better, if possible, to make every course in the masonry of a pier or pillar, in one stone. Large columns in a single block have a striking effect; but where a single block of sufficient size cannot be obtained, the next best arrangement is to have as few courses as possible, and the stones ought to be so selected and arranged as to conceal the joints as much as possible; choosing them of the same colour, and arranging the grain in one direction. [See Stone.] Vertical joints in columns ought not to be allowed.

In order to prevent the stones from slipping upon each other, and the joints from separating, it is necessary in some cases to insert between them a *cramp* or *dowel*, that is, a piece of iron, copper, or wood of a dove-tail form, as shown in Fig. 1417. These are inserted half in each stone, and the two having been placed, lead is run into the space round the dowel, which fixes it firmly to the stone. Dowels are sometimes made of hard stone, and are then run with cement. The ancients were accustomed to unite one stone with another by means of iron or bronze cramps, Fig. 1418, sometimes run with lead. The holes in the walls of the Coliseum and other monuments at Rome

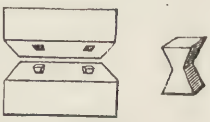


Fig. 1417.

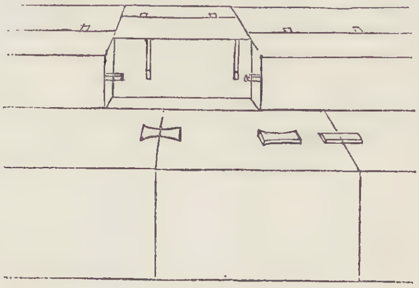


Fig. 1418.

have been drilled or cut for the purpose of extracting the bronze cramps that united the courses of masonry together. Oak dove-tails were used in the Parthenon at Athens for the same purpose. It is not a good plan to secure dowels by means of lead: it may be necessary with bad workmanship, but a good workman will prefer to trust to very close and workmanlike joints, carefully fitting dowels and fine mortar. Iron cramps, used as fastenings on the tops of

copings, &c., are very unsightly, and ought to be avoided: they are even injurious if exposed to the corroding action of the atmosphere, for they not only produce ugly stains, but will sooner or later burst and split the work they are intended to protect.

Stones are said to be *joggled* together when a projection is worked out on one stone to fit into a corresponding hole or groove in the other, as in Fig. 1419; and when the two stones are united only a vertical

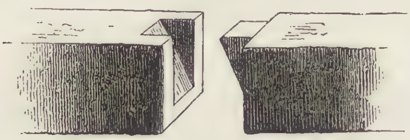


Fig. 1419.

joint will be seen. This plan occasions great labour and waste of stone; hence *dowel-joggles* are used: these are hard pieces of stone cut to the required size, and let into corresponding mortices in the two stones to be joined together.

The tools employed by the mason are different in different countries, according to the quality of the stone. In London, where stone is scarce, it is cut into scantlings by the saw, described under MARBLE, Fig. 1382. In places where stone is abundant it is divided into smaller scantlings by means of wedges. Hard stone and marble are reduced to a surface by a mallet and chisel. The mallet is similar to a bell in shape, except a portion of the broadest part, which is rather cylindrical: the handle is only just long enough to allow it to be firmly grasped in the hand. The chief implements in London for hewing stones are the mallet and tools. The tools are of iron tipped with steel, and the cutting edge is the vertical angle. The end of the tool struck by the mallet is a small portion of a spheric surface, and projects on all sides beyond the adjoining part or hand-hold, which increases in magnitude towards the middle of the tool, and thence tapers forward, in the form of a wedge or pyramid, to the entering or cutting edge. The other tools used by the mason are a level, a plumb-rule, a square, a bevel, and straight and circular rules of various descriptions for trying the surfaces as the work proceeds. In working the face of a stone the tools used in London are the *point*, the *inch-tool*, the *boaster*, and the *broad-tool*. The operation of working with a point is called *pointing*, and that with the boaster is termed *boasting*. The operation of the point leaves the surface in narrow furrows with rough ridges between them. The inch-tool is used in cutting away the ridges, and the boaster in making the surface of the work nearly smooth. The point is, in breadth, at the entering part, from $\frac{1}{8}$th to $\frac{3}{8}$ths of an inch, the boaster 2 inches wide, and the broad tool $3\frac{1}{2}$ inches at the cutting edge. In the use of the tool the cutting edge is always perpendicular to the same side of the stone. There are two kinds of operations performed with it: suppose the impression made by the whole breadth of the tool at the cutting edge to be called a *cavity*. In one operation, the successive cavities follow one another in the same straight line until the breadth or length of the stone is exhausted: these successive equidistant parallel lines are repeated in the same manner until the whole surface of the stone has been gone over by the tool. This method of hewing is called *stroking*, which is a kind of fluted surface. In the other operation every successive cavity is repeated in new equidistant lines throughout the length or breadth of the stone, then a new series of cavities is again repeated throughout the length or breadth of the stone, and thus, until the whole breadth or length of the stone is exhausted. This method is called *tooling*. Tools for working cylindrical and conical parts of mouldings are of all sizes, from $\frac{1}{8}$ inch upwards; but those for working convex mouldings are generally $\frac{1}{2}$ inch broad, unless in confined spaces, where such breadth cannot be admitted. A stone is taken for the most part out of winding with points, and entirely with the inch tool.

In London the facings of buildings made with squared stones are either stroked, tooled, or rubbed. In places where the sawing of stone by the use of the saw does not compensate for the loss of time taken up in sawing, the operation is entirely performed by the mallet and chisel.

When stones are very unshapely, a *stone-axe*, *jedding-axe*, *scabbling-hammer*, or *cavil* is used previous to the operation of hewing, in order to bring the stone nearly to shape. One end of the jedding-axe is flat, and is used for knocking off projecting angular points, and the other end is pointed, for reducing the different surfaces nearly to the intended form.

In some places the surfaces of the stones are formed with zig-zag lines, called *herring-bone*, already alluded to. In Scotland, in addition to hewn-work, there are other kinds, known as *droved*, *broached*, and *striped*. Droving is similar to random-tooling or boasting: the chisel for broaching is called a *punch*, instead of a *point*. Broached work is first droved, and then broached. Striped work is also first droved. In Aberdeen, where the hardness of the granite does not admit of these operations, a scabbling-hammer is used, by which the stone is *picked* until the surface is nearly of the intended form. This operation is termed *nidging*, and the work done, *nidged work*. Where the surface is smoothed by means of sand or grit stone, it is called *rubbed work*.

In forming a plane surface the mason first knocks off the superfluous stone along one edge of the block, as *a b*, Fig. 1420, until it coincides with a straight-edge throughout its whole length: this is called a *chisel draught*. Another chisel draught is then made along one of the adjacent edges, as *b c*, and

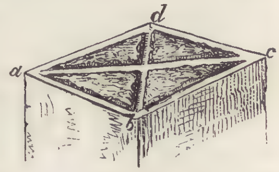


Fig. 1420.

the ends of the two are connected by another draught, as *a c*; a fourth draught is then sunk across the last, as *b d*, which gives another angle point *d* in the same plane as *a b* and *c*, by which the draughts *d a* and *a c* can be formed; and the stone is then knocked off

between the outside draughts until a straight-edge coincides with its surface in every part.

Various curved rules, or templates, and gages, are employed in hewn work. For example, in forming cylindrical or moulded surfaces, curved in one direction only, the mason sinks two parallel draughts at the opposite end of the stone, until they coincide with a mould or template, cut to the required shape; and he afterwards works off the stone between these draughts by a straight-edge applied at right angles to them. See Fig. 1421.

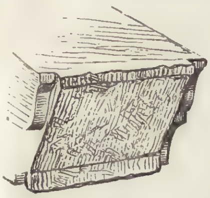


Fig. 1421.

In measuring masons' work, the cubic content of the stone is taken, without deduction for subsequent waste. If the scantlings be large, an extra price is allowed for hoisting. The labour in working the stone is charged by the superficial foot, according to the kind of work, as *plain work*, *sunk work*, *moulded work*, &c. Pavings, landings, &c., and all stone less than 3-inch thick, are charged by the superficial foot. Copings, curbs, window-sills, &c. are charged per lineal foot. Cramps, dowels, mortice holes, &c. are charged separately. A journeyman mason receives from 4*s.* to 5*s.* 6*d.* per day, and the labourer from 2*s.* 6*d.* to 3*s.* per day; but masons working at piece-work will often earn much more. The remuneration of a stone carver depends on his talent, which often rises to that of an artist, and is appreciated accordingly.

MASTIC, a resinous substance collected in the form of tears, from the *Pistacia lentiscus*, a small evergreen tree found in the south of Europe, the north of Africa, and the Levant. It is especially abundant in the island of Chios, where the mastic forms one of the most important productions. In order to collect it, numerous incisions are made in the trunk and branches of the trees, in the middle of July, and from these the sap gradually flows, and thickens by exposure to the air, generally adhering to the tree in the form of drops, but if very abundant, falling to the ground before it hardens. The tears which form on the bark are most esteemed, and are removed by a sharp instrument, cloths being spread beneath the tree to catch them as they fall. The first gathering is completed in eight days, after which fresh incisions are made, and the trees are left untouched until the 25th of September. The second gathering then begins, and is carried on at intervals until the 19th of November, when it ceases for the season.

The best mastic is translucent, of a pale yellow colour, vitreous fracture, and agreeable odour and taste. It is a valuable ingredient in several varnishes, and is also used for stopping decayed teeth. The inhabitants of the countries whence mastic is obtained, consider it highly efficacious in promoting a healthy state of the mouth, and constantly chew it for that purpose. It is this use of the substance which suggested its name, mastic being derived from *masticare*, to masticate.

Mastic forms a pale and brilliant varnish, when dissolved either in spirits of wine or oil of turpentine, the latter being most frequently used, on account of its cheapness. The best-picked mastic is used for this purpose; and if turpentine be employed, the proportion of mastic is three pounds to the gallon of turpentine. The mastic is dissolved by agitation, without heat, and the varnish thus made is strained and poured into a bottle, which is loosely corked, and exposed to the sun and air for a few weeks. A deposit takes place, from which the clear varnish is poured off for use; but the longer it is kept the better. This varnish is much used for paintings and other delicate works. It flows better on the surface than most other varnishes, but is liable to chill. This chilling results from the presence of moisture in the varnish; and to prevent it the following method is sometimes employed:—A quart of river-sand is boiled with two ounces of pearlash; the sand is then washed two or three times with hot water, and strained each time. The sand is then dried in an oven, and when of a good heat, half a pint of it is poured hot into each gallon of varnish, and shaken well for five minutes; it is then allowed to settle, and carries down the moisture of the gum and turpentine.

MATCH, an implement used in firing military mines or in discharging pieces of ordnance. The match may be *slow* or *quick*. The *slow-match* consists of a piece of slightly-twisted hemp, which has been well soaked in a strong solution of saltpetre. When lighted at one end it burns very slowly, a piece 1 yard in length being scarcely consumed in 8 hours. When in use it is revived by blowing upon it by the lips, when it will ignite gunpowder or the cotton wick of a fusee. In the formation of a *quick-match* the materials used are a mixture of saltpetre and mealed gunpowder with spirit of wine and distilled or rain-water. The water and the saltpetre are boiled for an hour with a cotton wick coiled up in the solution: the spirit is then added, and the mixture left to simmer for a quarter of an hour. Some of the powder is then added, and the whole left for 24 hours. The cotton is next wound upon a reel, and the rest of the powder sifted over it. After drying for some days the match is fit for use.

MATCHES. The comparatively low temperature at which sulphur ignites led to its being used at the end of a strip of wood as a means for procuring flame. The old tinder-box with its flint and steel, tinder and matches, was a troublesome, but ingenious arrangement. As it has now become a matter of history, a short description may be interesting to some readers. The tinder consisted of carbon in a filmy form, procured by burning a piece of rag in a short cylindrical iron box, called the *tinder-box*, the loose cover of which being inserted, extinguished the flame of the burning rag, and left the carbon. The steel was a strip of hard iron, curved round at the top and bottom, so as to form a handle: this was held in the left hand, and in the right a flint wedge, the sharp edge of which being struck against the steel, chipped off minute fragments: the heat developed by the percussion was

sufficient to ignite and even fuse these metallic fragments, which, falling down into the easily combustible carbon, ignited it at every point of contact. The operator then blowing upon the tinder to keep up the combustion, applied the point of one of the matches to the incandescent carbon, and, with some little contrivance, managed to ignite the sulphur, which, in its turn, ignited the wood of the match. The cover was then returned to the box, and the weight of the flint and steel pressing it down, extinguished the sparks in the carbon. The operation was not, however, always successful: the tinder or the matches might be damp; the flint blunt, and the steel worn; or, on a cold dark morning, the operator would not unfrequently strike his or her knuckles instead of the steel; a match, too, might be often long in kindling; and it was not pleasant to keep blowing into the tinder-box, and on pausing a moment to take breath, to inhale sulphurous acid gas, and a peculiar odour which the tinder-box always exhaled.

When, about the year 1673, phosphorus was discovered, and its easy ignition by mere friction made known, all persons who could afford to procure the costly novelty did not fail to do so. A minute portion of it rubbed for a moment between the folds of brown paper took fire, and ignited a sulphur match applied to the flame. In 1680, Godfrey Hanckwitz, at his laboratory in Southampton-street, Strand, manufactured and sold large quantities of phosphorus for this purpose; and so great was the fame of the new method, that Godfrey set out on his travels to exhibit and sell the article. The costliness of phosphorus probably prevented its general introduction; and it is remarkable that a century and a half should have elapsed before this substance should have come into general use for our best and readiest form of match. It cannot, however, be said that during this long period phosphorus was altogether neglected as a means for procuring a light. *Phosphoric tapers* were for some time in use: they were small wax tapers, the wicks of which were coated with phosphorus: they were enclosed in glass tubes hermetically sealed, and when a light was required, one end of the tube was cut off with a file, and the taper took fire on exposure to the air. This plan, however, was found to be inferior to friction with brown paper, and in some cases it was dangerous, so that it soon became forgotten. The next plan was to put a piece of phosphorus into a small phial, and then to stir it about with a hot iron wire: the phosphorus was partially burnt in a confined portion of air, and the interior of the bottle covered with oxide of phosphorus. On removing the wire, the phial was corked tightly for use. When a light was wanted, a common sulphur match was dipped into the bottle, and a small portion of the phosphorus adhering to the tip, flame was produced by the energetic chemical action of the sulphur and the phosphorus. This plan was for a long time a favourite one, and the writer remembers these bottles being hawked about the streets of London. Another method was to rub the match, after dipping it into the bottle, against a piece of cork or soft wood, the friction more certainly promoting the combination of the sulphur and phosphorus, and the consequent production of flame.

Another method of kindling a match was by means of *Homberg's pyrophorus*, or fire-bearer: it was a black powder, produced by the calcination of flour, sugar, and alum, which took fire on exposure to the air. A small bottle of this powder, if well prepared, lasted a good while, and was a convenient method of getting a light, but one not likely to get into general use. It was chiefly in the hands of the curious. Its action was unknown until the discovery of potassium, when it was evident that this metal, evolved from the potash of the alum by the action of the charcoal of the flour and sugar, on being exposed to the air, absorbed oxygen, and had its temperature raised sufficiently to make the minutely-divided carbon incandescent.

The first *instantaneous light-machine* was the "inflammable air-lamp of Volta," as it was called. This consisted of a glass reservoir filled with hydrogen gas, which could be subjected to the pressure of a column of water on turning a stopcock. The pedestal upon which the reservoir was placed was an electrophorus, and the apparatus was so adjusted by connecting-wires, that, on turning the cock, a small stream of hydrogen rushed out, and met an electric spark from the electrophorus, which ignited it, and the flame thus produced lighted a match or taper placed directly against it. This apparatus soon became a favourite with scientific persons; but it was found that in consequence of air getting into the hydrogen reservoir it had a tendency to explode. It was therefore abandoned, and in after years the Dobereiner lamp, described under HYDROGEN, took its place.

Many years ago, the question was much discussed among chemists, whether the sudden compression of a volume of atmospheric air, or oxygen, was sufficient to produce a luminous effect in consequence of the heat evolved. It was admitted that a flash of light accompanied the sudden condensation of oxygen; but this was referred by Thenard to the ignition of the oil with which the apparatus was lubricated. Supposing this to be the case, it occurred to some ingenious man to employ this flash of light in igniting a piece of amadou or German tinder. This led to the invention of "the pneumatic tinder-box, or light-syringe." It consisted of a stout brass syringe, about 6 inches long and half an inch in diameter, closed at one end, and fitted with an air-tight piston, at the lower extremity of which was a cavity for containing a piece of amadou. By suddenly driving the piston into the tube, the air contained within it was compressed, its capacity for heat diminished, and consequently enough heat was liberated to ignite the tinder. On quickly drawing out the piston, and blowing the tinder into a glow, a match could be ignited, and sometimes a cigar. On being first introduced, the novelty and ingenuity of the contrivance excited attention, and vast numbers of the fire-syringe were sold; but when it was found that several conditions were necessary for success, such as dry tinder, an accurately-fitting piston, considerable strength of arm,

and a peculiar knack, the apparatus was declared to be more troublesome than useful, and fell into disuse. It may now be seen occasionally on the table of the scientific lecturer, to whom it gives the means of performing a beautiful and instructive experiment.

Another scientific method of lighting a match was by means of voltaic electricity. A plate of zinc, two inches square, and a double plate of copper, dipped into a small cistern of dilute acid, afforded a current of sufficient power to ignite a fine platinum wire connecting the copper and zinc plates. On touching this wire with a piece of touch-paper, it instantly ignited, and from this a match could be kindled; the direct contact between the sulphur and the hot wire being avoided on account of the tendency of sulphur and platinum to combine at high temperatures.

But of all the ingenious attempts to get rid of the old tinder-box, the *oxymuriate matches*, as they were called, were the most successful. From them our present *lucifers* are lineally descended, and they therefore deserve a respectful notice. The oxymuriate matches were based upon the fact that when oxymuriate, or more properly chlorate, of potash is mixed with sugar or other inflammable substance, it suddenly bursts into flame on the contact of a drop of sulphuric acid. Small portions of this mixture in powder were first used for the purpose of getting a light; but it was soon found that if mixed with gum, and made up into a paste with a little vermilion for the sake of the colour, strips of wood tipped with this composition, ignited on being dipped into a bottle containing a piece of asbestos soaked in strong oil of vitriol. The bottle, and a number of matches with the tipped ends downwards, were put into a neat little case of *moirée métallique* (a beautiful invention just introduced), and this was called a *phosphorus-box*. Although it contained no phosphorus, it had *light-bearing* or *light-giving* properties, whence we suppose the name, just as our *lucifers* are *light-bearing*, only in this case we get our derivation from the Romans, while in the former it is from the Greeks. On their first introduction the phosphorus boxes were sold as high as 15*s*. each; they gradually fell to 10*s*., 5*s*., and 2*s*. 6*d*. for a small box, at which last price they continued for some years.

There were, however, some inconveniences in the use of these matches. When in perfect action the sulphuric acid suddenly decomposed the chlorate paste with a considerable rise in temperature, and the evolution of oxygen, which entering into combination with the inflammable elements of the sugar produced flame. But in some cases, where the acid had become weak by absorption of moisture from the air, the match, instead of bursting into flame, merely smouldered and spirted the acid about, sometimes to the ruin of a lady's dress. It might also happen that if the match on being dipped did not act immediately, it was economically returned to its case and another selected: but the wetted match, thus returned, coming in contact with another and more energetic match, caused it to burst into flame, and thus the whole collection of matches was ignited at once, and shot out in all directions. To remedy this the maker, instead of putting the tips of the matches downwards, as heretofore, placed them upwards: but this did not much mend the matter, for, on getting a light in the dark, the match, on being taken out of the bottle, was not unlikely to communicate acid or flame to its companions. This defect was also remedied by placing the matches in a horizontal position under a tin cover, with printed directions to shut down the cover on taking out a match, and to throw it away if it did not ignite. The matches were improved by tipping them first with sulphur, and then with the chlorate paste, which made them ignite more readily. Camphor and frankincense were sometimes mixed with the paste, and the wood of the match was of cedar, so that a pleasant odour was diffused in getting a light. But there were defects still to be remedied. The cork of the bottle became rotten from the effects of the acid, and the acid became weak by absorption of moisture. A glass stopple was therefore substituted for a cork, and in order more effectually to exclude the air a glass cap was made to fit over the neck of the bottle. In some cases the stopple was elongated, so that, instead of having to dip the match into the bottle, all that was necessary was to touch the tip of the match with the tip of the stopple. A plug of India-rubber was also used instead of a stopple or cork.

That there was still ample room for improvement in this invention will be admitted from the fact, that the box cost half-a-crown, and the matches a shilling per hundred. This was not likely to be a very successful rival to the old tinder-box. Many of our readers will probably remember the notice posted and advertised so abundantly — "Save your knuckles, time, and trouble: use Heurtner's EUPYRION, *Price One Shilling!*" This invention consisted of 2 tin cases soldered together, each about 1¼ inch square, but of different depths; one being 3 inches, and the other about 1 inch deep, the longer compartment holding the matches, and the shorter one the little bottle of acid, so that, not being on the same level, there was less chance of an accident. The cork was covered with thin lead to prevent corrosion; the acid was strong, and the match-composition good, so that there was much to recommend this invention, and it sold largely.

But the Eupyrion shared the fate of all other useful inventions which admit of being simplified and economised. It was superseded by the *lucifer-match*, which still reigns triumphant. The original lucifer-match was tipped with a paste consisting of chlorate of potash and sulphuret of antimony mixed up with starch, and its great value consisted in igniting upon being drawn across sand-paper. There were, however, objections to these early matches: they required so much pressure to produce the necessary friction, that the top was often pulled off without igniting, and when ignited, burst into a violent flame, and often spirted out sparks of kindled matter which were dangerous: moreover, the sulphurous antimonial vapour was highly offensive to persons with weak lungs: the manufacturers were also liable to serious

accidents from the contact of chlorate of potash and sulphur.

The substitution of phosphorus for the sulphuret of antimony was a great improvement introduced about the year 1834. But before this, Mr. Jones, of "the Lighthouse" in the Strand, invented the *Promethean.* This consisted of a small coil of waxed paper, in one end of which was a portion of sulphuric acid hermetically sealed in a minute glass bulb, and surrounded with the chlorate of potash-paste. When the end thus prepared was crushed with a hammer, or by means of a pair of nippers provided for the purpose the acid was brought into contact with the composition, and a burst of flame was produced. For the benefit of cigar smokers prometheans were made with touch-paper, which, instead of inflaming, burnt like a slow-match.

The introduction of phosphorus into the lucifer-match led to several decided improvements: saltpetre was substituted, either wholly or partially, for chlorate of potash, thus producing quiet ignition instead of detonation: the ill odour was got rid of by omitting much, if not all the sulphur, and using stearine instead. Machinery was introduced for cutting the wood into splints so as to ensure uniformity in the size: other materials also came into use instead of wood, such as *wax-taper matches*, *fusees* of amadou or brown paper, *Vesuvians* for lighting cigars, and some other forms.

Having recently inspected with some care the processes concerned in the manufacture of lucifer-matches, we now propose to give a detailed notice of them.[1] We offer no excuse for the length of this article, for the subject of it, however apparently trivial, has really become an important branch of industry. The factory which we have visited produces upwards of *two millions* of lucifer-matches every day; and we learn from the Jury Report, Class XXIX., that, in 1849, Austria manufactured 50,000 cwts. of matches, of which 4-fifths were consumed in the country and 1-fifth exported: that the materials consumed in one year in Austria in this manufacture were, of nitre, 1,250 cwts., of phosphorus, 325 cwts., and of sulphur, 15,000 cwts. Other parts of Germany, France, Great Britain, and the United States of America, also produce vast quantities of matches. In Austria the export trade is greatly on the increase.

The wood employed in the manufacture of lucifers is the best pine plank, as free from knots as it can be procured. Each plank is cut across the fibres by means of a circular saw, into 28 or 30 blocks, each measuring 11 inches long, 4½ wide, and 3 inches thick. These blocks are cut up into splints by a machine of simple but ingenious construction, which we will endeavour to explain in a few words. To the extremity of the horizontal arm of a crank is attached a frame, which reciprocates to and fro with the motion of the crank through a space of about 4 inches. In this frame are fixed in a line some 30 or 40 lancets with the points projecting upwards, and separated from each other by pieces of brass. The block of wood to be cut is inserted by the small end between uprights, and a lever placed upon it forces it down to a position such, that as the lancet points advance, the end of the wooden block is scored or cut in the direction of or parallel with the fibres, with as many lines as there are lancets. As the lancets are withdrawn by the motion of the crank, a scythe blade moving in a horizontal plane swings round, and cuts off the end of the block to the depth of the scores made by the lancets. The pieces thus cut off will evidently be 4-sided splints, square in section, supposing, as is the case, that the lancets are equidistant, and that the horizontal knife cuts exactly to the depth of the lancet scores. When the horizontal knife swings back, the block, from which one layer of splints has thus been removed, descends through a space equal to the depth of the section, the lancet points again advance and recede, and the knife again does its work. In this way the cutting is carried on with such rapidity, that from 12 to 16 planks, each 12 feet long, 11 inches wide, and 3 inches thick, can be cut up into splints in a day of 10 hours. Now, supposing 14 planks are thus cut up, and that each plank produces 30 blocks, we thus get $14 \times 30 = 420$ blocks. Each block affords about 100 slices, which are cut off by the horizontal knife, but as each slice before being cut off has been scored by 31 lancet points, we thus get $420 \times 100 \times 31 = 1{,}302{,}000$ splints, and as each splint makes two matches, we thus have 2,604,000 single match splints per day.

When a circular instead of a square section is required, the wood is cut into splints by means of a perforated metal plate, the perforations being so shaped as to cause the block of wood when pressed against its face, to be properly divided. Fig. 1422 shows the face of the plate, and Fig. 1423 a vertical section of the same. The perforations are cylindrical

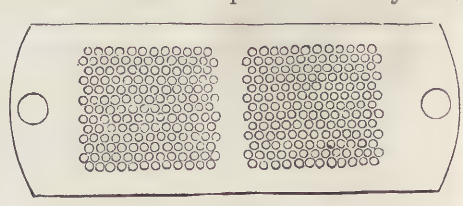


Fig. 1422.

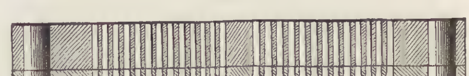


Fig. 1423.

throughout, except at their openings on the face, where they are slighly countersunk for the purpose of presenting sharp-cutting edges to the wood, and affording a more easy entrance. The perforations are made as close together as possible, that all the wood may be used, only sufficient metal being left to afford the necessary strength for cutting. The plate has a steel face and a bell-metal back; it is 3 inches wide, 6 inches long, and about 1 inch thick. The back is fixed against a firm resisting block or bearing, with an aperture equal to the area of the perforations of

(1) Our thanks are due to Mr. Hynam of Princes-square, Finsbury, for permission to visit his factory.

the plate. The piece of wood being placed on end in the direction of the fibres, the plate is forced down upon it by means of a plunger or lever, when the splints appear at the back of the plate, whence they are removed before another block is applied. This plan was patented by Mr. Partridge in 1842.

We now return to the square match. As the splints fall off the end of the block by the action of the horizontal knife, they pass down a shoot immediately under the block into a room below, where they are tied up into bundles, each containing half a gross. For this purpose, a cradle or measure is formed consisting of a section of a hollow cylinder of the capacity of half a gross of splints of the proper size, either for the *large* splints or the second size called *minnikins*, these being the only two sizes made at this factory. The man begins by throwing a piece of string across the cradle, then taking up a number of splints from the confused heap, he ranges them in parallel order by a dexterous system of tossing, knocking, and jerking; having filled his measure, he catches the two ends of the strings, ties up the bundle, throws it aside, and then proceeds to make another, the work being done with the rapidity and precision which practice alone can give. These bundles are piled up on the racks of a hot room or drying stove, and left for some hours until moisture is expelled.

The next process is the *sulphuring*. The sulphur is melted in an iron pot over a stove, and when sufficiently fluid, the two ends of the bundles are successively dipped, the bundle being shaken after each dipping, in order to get rid of superfluous sulphur. When the sulphur is dry, a second string is tied round each bundle, so that when divided by the circular saw, each bundle of double matches may make two bundles of single matches. Some of the matches, however, are not divided until after having been tipped with the phosphorus composition; but this is merely a matter of convenience to the makers.

The matches are now ready for dipping in the phosphorus composition. We were not informed as to the precise ingredients of the composition, or the method of mixing. Each manufacturer professes to have his own recipe, which he regards as the best, and therefore keeps secret. The ingredients are, however, well known to chemists: the principal one is phosphorus, which is made into an emulsion with glue or gum arabic, the former being preferable, since gum absorbs moisture. Some makers use nitre, others fine sand; and all use colouring matter, which may be red ochre, red lead, smalt, or artificial ultramarine.

The following proportions have been found to answer:—

	Glue paste.		Gum paste.
Phosphorus	2·5	......	2·5
Glue	2	Gum	2·5
Water	4·5	......	3
Fine sand	2	......	2
Red ochre	0·5	......	0·5
Vermilion	0·1	......	0·1

Instead of the last two colouring substances 0·05 of Prussian blue may be used.

When glue is used it is of very inferior quality: it is broken into fragments and soaked for a few hours in cold water; then dissolved in a large glue pot, or copper C, Fig. 1424, heated by a water bath W. When it is perfectly fluid and at the temperature of 212°, the copper is withdrawn and placed in the circular opening of the frame, Fig. 1425. The phosphorus is then added by degrees: it melts immediately

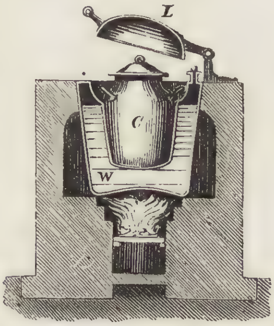


Fig. 1424.

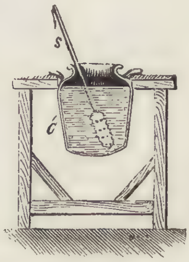


Fig. 1425.

and subsides, but is kept in agitation by means of the wooden stirrer *s*, which is furnished at the lower part with projecting pegs, the object being as the glue cools to obtain an emulsion of phosphorus in a minutely divided state. The sand and colouring matters are added during the stirring. The paste is kept at the temperature of about 98°, sufficient to retain it in a fluid state by placing the vessel C in a water bath.

When the paste is made with gum it remains fluid at ordinary temperatures, which is an advantage, but it is seldom used on account of its hygrometric properties. In preparing the gum paste the weighed or measured solution of gum is put into the copper C, and heated to 212° as before; then removed to the frame, Fig. 1425, where the phosphorus is added and beaten up into an emulsion until cold. The other substances are added last.

Dr. Böttger gives the following recipe for a paste common in Germany:—Phosphorus 4 parts, nitre 10, fine glue 6, red ochre or red lead 5, smalt 2. The glue to be converted into a smooth jelly with a little water; the phosphorus to be rubbed down with it at a temperature of from 140° to 150°; after which the nitre is to be added, then the red powder and lastly the smalt, the whole to be carefully mixed into a uniform paste.

The matches are prepared for dipping by a number of children, who proceed in the following manner:— untying one of the bundles of sulphured matches, the child standing before a very narrow frame, composed of two uprights and a bottom cross piece, places upon the latter and between the uprights, a narrow board containing 50 grooves across it about half an inch apart. Taking a handful of matches the child quickly deposits a match in each groove, the board being so narrow that the ends of the matches project considerably on each side: she then places a piece of stout list along the board upon the middle of the matches; upon this another grooved-board, which in like manner is filled with 50 matches; then another

strip of list; and in this way the boards are piled up to the top of the frame, and when 24 rows are filled, a top cross-piece is put on and secured by thumb screws, or by tying with string. The frame is then taken in both hands: the ends of the matches are knocked against the table evenly into one plane, and it is then ready for the dipper.

The match composition is spread out with a spatula in a thin layer upon a stone slab which is heated by steam below to keep the glue sufficiently fluid, and a man standing besides it takes a frame in both hands, and presses the sulphured ends of the matches down upon the slab; then turns them up to see that they are properly dipped, and if necessary dips them a second time. He then places the frame upright upon one of its sides upon a table near, from which it is taken by a boy into a room heated by a stove and a hot flue. When sufficiently dry the frames are removed to the filling room, where a number of little girls stand at a table, which occupies the sides of the room, with the frames of matches inclining against the wall. The top cross-piece and the list being removed, the child sweeps off the row of 50 matches, catches up a box, slips it partly out of its 4-sided case, dashes in the matches, closes the box and deposits it in its place among a pile of boxes already filled. She then takes off the empty board and the piece of list below it, and fills another box, this series of operations being performed so rapidly that the writer could not count 10 deliberately, in the interval between the filling of 2 boxes. In a day of 10 hours, a quick hand can dispose of 150 frames, or 3,600 boxes. It occasionally happens that in sweeping off a row of matches, a match ignites and kindles the others in the row; the girl has a box of sawdust at hand in which to plunge and extinguish the flames.

Fusees for lighting cigars are also made at this establishment. The strips of pulp, *i.e.* thin card-board prepared by steeping in nitre, are sent from the cutting room to a room where 4 girls are engaged in the following operations: the maker's name is first stamped on each strip; a girl then takes 25 strips in her hand, and with a stick shaped like a paper-knife takes up a portion of the red composition and spreads in over the cut extremities of the top strip; places this on the table, and in like manner covers the ends of the second strip, and so on till the 25 are prepared. In the mean time another girl takes these strips, and twists them so as to separate the fusees from each other, and arranges them on a tray, which when full is placed on a rack to dry. After this the strips are made up in packets of 1,000 each.

In the drying of the lucifers and fusees, a portion of the phosphorus is converted into phosphorous acid, and escapes into the room; as the glue hardens and solidifies, it forms a protective coating to the remainder of the phosphorus, and prevents it from oxidizing by exposure to the air. If we chip off a piece of the composition from a fusee by pressing the thumb nail against it, the slight friction and the sudden access of oxygen cause it to burst into flame; so also by rubbing the end of a lucifer match against a hard substance, the protective glue coating is worn off, and the heat excited by the friction kindles the composition, which fires the sulphur and this the wood of the match.

The acid fumes which are given off by the phosphorus during the mixing, the dipping, and the drying, render the work-people liable to a very painful disease, which in Germany has led to such shocking results, as to call for inquiry on the part of the Government. The disease is in the jaws; it commences with pain and swelling, and is followed in many cases by exfoliation of the bone. The cause seems to be in the vapour of phosphorous acid, which first attacks the teeth and then the jaws through the sockets. The persons most liable to this disease are the dippers, in consequence of their standing for hours together over the heated slab upon which the phosphorus composition is spread. It appears from medical evidence that a continued and uninterrupted occupation in an atmosphere highly impregnated with phosphorus fumes is a necessary condition in the production of the jaw disease; but that if the factory be well and abundantly ventilated, cleanliness in the work-people enforced, together with attention to diet, no evil consequences ensue. In the factory which we have visited the workpeople are required to wash their hands night and morning in a solution of soda; the dippers wear sponges before their mouths, and an accumulation of fumes is prevented by numerous open windows, fan-lights and ventilating shafts. The gentleman who conducted the writer over the factory evidently took an honest pride in pointing out the abundant provision for ventilation, and the healthy appearance of the men, boys and girls. One man had been employed in the mixing room for 13 years, a dipper had been at work 10 years, a girl employed in tipping fusees 8 years, other girls 4 years, and so on. We were assured that not a single case of jaw disease had occurred, that the people were unusually healthy, as indeed the appearance of the majority seemed to testify. The only part of the factory that was decidedly oppressive was the drying room, which is kept at a temperature of about 90°, and was full of fumes. There are, however, only two boys employed here; one to take the frames in to dry, and the other to fetch out when dry.

There are factories in London less happily distinguished than Mr. Hynam's, where the jaw disease is known, as our hospitals can testify. It is stated by medical men that such factories are deficient in the excellent precautions which we have enumerated. We regret this, because as it is clearly the duty of every employer to protect his work-people from injury, as far as lies in his power, the neglect of such duty becomes positively sinful, if the means of salubrity be pointed out, and he neglect to adopt them.

The allotropic phosphorus noticed in our *Introductory Essay*, p. cxxxviii., does not appear to have yet found its way into the lucifer-match factory. If it could be successfully applied, it would get rid of all the objections to the use of phosphorus; but we should be sorry to see this remarkable form of phos

phorus used as an excuse for neglecting efficient ventilation, without which no workshop, factory, schoolroom, parlour or bedroom, or any other similarly enclosed space, can be a fit habitation for man or beast.

MATRASS, a glass chemical vessel with a thin oval bottom, used for the purpose of digesting, boiling, and distilling. In the last operation, one matrass

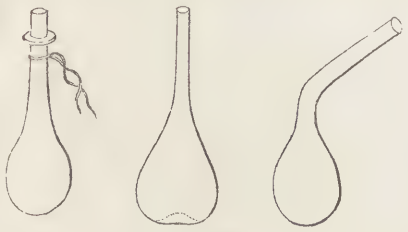


Fig. 1426.

may be used as the body, and another as the receiver. Florence flasks make excellent matrasses. Fig. 1426 shows three useful forms of matrass: the centre one is flattened a little at bottom.

MATRIX. Metallic ores are usually associated with stony substances, which form what is called the *matrix* or *gangue*. The *earthy gangues* are usually quartz, felspar, limestone, carbonate of barytes, sulphate of lime, sulphate of barytes, and fluor spar. In some cases, ores become gangues with respect to more precious metals, forming what are called *metallic gangues*, such as iron pyrites, spathose iron ore, oxide of iron, hydrate of iron, and blende. [See GANGUE.] The mould used in type-founding, is also called the *matrix*. See PRINTING.

MATTE, the crude black copper, reduced but not refined from sulphur and other substances. See COPPER.

MEAD, a favourite drink of the early inhabitants of the British Islands, and probably the only strong liquor known to them during a long period. It is made with honey mixed with water and fermented.

MEAL, the edible part of wheat, oats, rye, barley, and pulse of different kinds ground into a kind of coarse flour.

MEASURES. See WEIGHTS and MEASURES.

MECHANICAL POWERS. See STATICS.

MECHANICS is the science which treats of the actions of bodies on one another, either directly or by means of machinery. These actions may be simple pressures without motion, as when one body being supported, another is placed upon it, either vertically or in some oblique position. The actions may be accompanied by motion, either from the mutual attractions which all bodies in nature exert upon each other, or from the collisions of bodies in motion with others, which may be previously in motion or at rest. When these actions refer to solid bodies, the phenomena are discussed in those subdivisions of Mechanics termed STATICS and DYNAMICS, under which heads they will be briefly noticed. When they refer to fluids, they belong to the subdivisions HYDROSTATICS and HYDRAULICS, to which we refer. When they relate to airs, they are treated of under PNEUMATICS. See AIR—BAROMETER.

MECONIC ACID. See OPIUM.

MEDAL, a coin struck or cast for some special purpose, such as to commemorate a victory, treaty, coronation, or other event, or in honour of some distinguished person. The words *medaglia* and *medaglione* first occur in Italian writers, and from them the English and French get their *medal* and *médaille*. The word is supposed to be from the Greek *μέταλλον*, metal, of which medals are always made. The metal used is generally bronze, [See BRONZE,] and the press in which they are stamped is similar to the coining-press. [See COINING.] A medal of extraordinary size is called a *medallion*.

MEERSCHAUM. See MAGNESIUM.

MENSTRUUM, the vehicle by means of which bodies are rendered liquid. See SOLUTION.

MENSURATION is the art of finding any dimension of a figure, or its area, or surface, or solidity, &c. It is one of the applications of arithmetic to geometry; but only the simplest measurements that the case will admit of are used.

MERCURY (Hg 100) is a brilliant white metal, possessing the remarkable and peculiar property of being fluid at common temperatures. This, together with its resemblance in colour to silver, has led to the terms *hydrargyrum*, *argentum vivum*, and *quicksilver* applied to it. It becomes solid at — 40°, in which state it is malleable, flattens readily under the hammer, and can even be struck into medals. At lower temperatures it becomes brittle. Within the arctic circle, the cold is often sufficiently intense to freeze mercury. The readiest method of doing so artificially, is by a solution of solid carbonic acid in ether. A temperature sufficiently low for the purpose may also be obtained by means of a mixture of pounded ice and crystallized chloride of calcium. In operating upon a small quantity of mercury in a large platinum crucible, which must be gradually cooled in successive freezing mixtures, the mercury may be obtained in a crystalline form. When the mercury has formed a solid crust, which adheres to the crucible, the fluid mercury in the interior is poured off, and the interior will be found lined with sharp brilliant crystals, which are regular octahedrons. When frozen mercury is brought into contact with the skin, it abstracts the heat very rapidly, destroys the vitality of the part, and produces the effect of a burn. Mercury contracts considerably in solidifying. At a temperature a little below freezing point, its density is 14·4.[1] At 32° its density is 13·596; at 60°, 13·568. It boils and becomes vapour at about 660°, and the density of its vapour is 6·976. It emits vapour at all temperatures above 40°. The volatility of mercury at ordinary temperatures, may be made evident by placing a daguerreotype plate several inches above a vessel containing mercury. If the plate has been previously iodized, and submitted to the action of light in the camera, the picture will be developed by the vapour of mercury at ordi-

(1) Mr. Phillips in his Manual of Metallurgy gives 15·612 as the sp. gr. of frozen mercury.

nary temperatures. The globules of mercury which condense in the upper part of the Torricellian vacuum of barometers, are a further proof of the volatility of mercury. It has been supposed that below 40°, the elasticity of mercurial vapour is scarcely sensible, for if a strip of gold leaf be suspended in a bottle containing a little mercury at the bottom, and be kept at temperatures ranging from 40° downwards, the leaf will not be whitened by the action of the mercurial vapour, except a few lines above the surface of the mercury: the rest of the leaf will preserve its characteristic yellow colour. Above 40° it will be converted into an amalgam. According to Brame, sulphur in the very finely divided utricular condition in which it is first precipitated from the state of vapour, is a much more delicate test of the presence of mercurial vapour than gold leaf; for by its means he finds that at 12° the vapour of mercury rises to a height of more than a metre, and that even at 8°, it appears to have no limited atmosphere, and that it rises at ordinary temperatures from amalgams and mercurial ointment. The following fact, as stated by Burnett, (*Phil. Trans.* 1823,) shows the danger arising from exposed metallic mercury. Part of the cargo of a ship on the Spanish coast was mercury contained in bags, which becoming rotten, the mercury escaped into the hold, where it mixed with the bilge-water; an elastic fluid was consequently formed, which covered the metal on board with quicksilver, and affected the whole ship's company with violent symptoms of salivation. We have also heard of the health of a whole family being seriously injured in consequence of a quantity of mercury spilled on the floor by a former tenant, finding its way under the boards, where it was left until discovered by the medical attendant of the family referred to.

When pure mercury is shaken up with water, ether, or oil of turpentine, or rubbed with sulphur, sugar, chalk, lard, conserve of roses, &c., it is reduced to a state of minute division, forming a grey powder, which unites with the foreign body, and in some cases, all appearance of the metal is lost. In well made mercurial ointment, the globules of mercury cannot be distinguished by the naked eye, for according to Ehrenberg, they are not more than from $\frac{1}{800}$th to $\frac{1}{1000}$th of a line in diameter. It is highly probable that the efficacy of mercury as a medicine, depends upon this state of mechanical division, and not to any chemical combination with chalk, lard, conserve of roses, &c., which merely serve as vehicles for the minute globules, and prevent their running together. In its ordinary state, mercury is inactive as a medicine, but in the minutely divided state, in which it exists in mercurial ointment, blue-pill, *hydrargyrum cum cretâ*, &c., the mercury is absorbed, and becomes active. The energetic action of mercury on the animal system, is shown by the nervous tremblings, salivation, and other morbid effects which it produces on the workpeople, whether in the mine or the factory, who are constantly or frequently exposed to it. And here again we see that mercury is energetic in consequence of the production of vapour, whether at ordinary temperatures or at a furnace heat.

Mercury is imported into this country in leathern bags, and also in bottles of hammered iron, containing 60 or 70 lbs. each. In this state the metal is very pure, but when purchased in smaller quantities, it is sometimes found to be adulterated with tin, lead, or bismuth, which metals are readily dissolved by mercury without much loss of fluidity. The fraud can be detected by subliming a little of the mercury in an iron spoon, when a residuum is left, which is not the case with the pure metal. Pure mercury does not adhere to glass or porcelain, but rolls upon those substances without leaving any trace; but when it contains foreign metals, it adheres to those surfaces, and in pouring leaves a train or *tail* behind. The pure metal forms spherical globules if moved about on glass, the adulterated mercury forms elongated tears covered with a grey pellicle, which adhere to the surface.

Mercury is of great value in the construction of philosophical instruments, on account of its fluidity, its great density, and the regularity of its expansion and contraction under the influence of increased and diminished temperatures; hence it is preferred to all other liquids for filling thermometer and barometer tubes, but for these purposes it ought to be pure. We will therefore describe somewhat minutely the various methods of purifying it. One method is to distil it, for which purpose one of the bottles in which it is imported may be used. It should be half filled with mercury, some clean iron or copper filings added, and the mouth fitted with a curved iron tube, to the further extremity of which is tied a tube or hose, formed of a number of folds of linen or cotton cloth. The end of the hose is to dip into a vessel of water, and a stream of water is also to be directed down the hose, as shown in Fig. 1427. On applying heat to the iron bottle, the mercury boils, and disen-

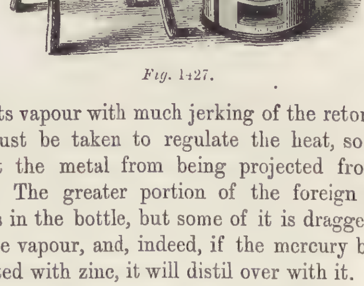


Fig. 1427.

gages its vapour with much jerking of the retort, and care must be taken to regulate the heat, so as to prevent the metal from being projected from the bottle. The greater portion of the foreign metal remains in the bottle, but some of it is dragged over with the vapour, and, indeed, if the mercury be contaminated with zinc, it will distil over with it.

The purification of mercury by distillation being thus imperfect, other modes have been adopted. The mercury may be treated with common nitric acid

diluted with about twice its volume of distilled water, and then heated to about 110°. Nitrate of the protoxide will be formed, and this, and the free acid, will react on the foreign metals, which are held in solution in the form of salts: any oxide of mercury is also dissolved. The action is continued, with occasional stirring, for 24 hours. The water is then separated by evaporation, and the nitrate, which forms a crystalline crust on the surface of the metal is removed. The metallic mercury is separated, washed with distilled water, dried with blotting-paper, and if necessary, placed under a glass containing a little quick lime, which completes the drying.

If the mercury is merely contaminated with oxide it may be cleansed by putting from half an inch to an inch in depth into a large earthenware pan, and pouring over it sulphuric acid diluted with twice its weight of water. This is allowed to remain for a week, being often agitated during that time: the metal and the acid are then separated, and the former washed, dried, and cleansed mechanically. A little sulphate of mercury assists the action of the sulphuric acid on the metal. Mercury may also be purified from dust, dirt, thin films of oxide, and other mechanical impurities, by folding a piece of paper into the shape of a cone or funnel, and passing the mercury through it. The opening at the bottom should be extremely small, but capable of being easily regulated: by pulling the inward fold upwards it increases the aperture below; but by pulling the outer fold upwards a little it tends to close it. The aperture may also be opened or closed more or less by the finger. The mercury, running through this cone into a glass vessel placed to receive it, leaves behind a quantity of scum and other extraneous matters: these abound so much in the latter portions of the mercury, that it is better to reserve these in the cone, and put them away for further purification. This simple method is sufficient for general purposes, where the impurities are merely adhering dirt, but other methods are likewise employed, such as filtering through the pores of a piece of hazel-wood by atmospheric pressure, or squeezing through chamois leather. After all, a film generally remains on the surface, but this may be greatly lessened by putting some powdered loaf-sugar into a bottle with the mercury to be cleansed, and agitating them well together. The effect is assisted by breathing into the bottle several times to give moisture, which causes the sugar, when agitated, to adhere better to the dirt present. After this the mercury is poured through a paper funnel, and is found comparatively clean.

Where small quantities of mercury have to be acted on, they may be purified by a simple process employed by Dr. Priestley, and which we shall describe in his own words:—"I take a glass phial with a ground stopper, (such being generally pretty strong,) and fill about 1-fourth of it with the foul quicksilver; then, putting in the stopper, I hold it inverted and shake it violently, generally striking the hand that supports it against my thigh. When I have given it 20 or 30 strokes in this manner, I take out the stopper, and blow into the phial with a pair of bellows, which I do in order to change the air, knowing that the purer the air the faster the process advances. After a short time, if the mercury be very foul, the surface will not only become black, but a great quantity of the upper part of it will be, as it were, coagulated, so as to be easily separated from the rest. I therefore invert the phial, and covering the mouth of it with my finger, let out all the mercury that will flow easily, and put the black coagulated part into a cup by itself. This I press repeatedly with the end of my finger till I make a complete separation of the running mercury from the black powder; and putting the powder by itself, I pour back the mercury to the rest of the mass out of which it was taken, in order to be agitated with it again. This process I repeat till I find that no more black matter can be separated; and it is not a little remarkable that the operator will be at no loss to know when the process is completed. For the same quantity of lead seems to come out of it in equal times of agitation, and consequently the whole becomes pure at once. Also, whereas, while the lead was in the mercury it felt, as I may say, like soft clay, the moment the lead is separated from it, it begins to rattle as it is shaken, so that any person in the room may perceive when it has been agitated enough." By subsequent distillation it was ascertained that mercury is perfectly purified by the above process.

Mercury is acted on very unequally by the mineral acids. Hydrochloric acid scarcely attacks it even under the influence of heat; nor has dilute sulphuric acid any action on it; but in its concentrated form, this acid, heated, forms with mercury a sulphate with disengagement of sulphurous acid. Nitric acid attacks mercury at all temperatures, and when the acid is diluted binoxide of nitrogen is disengaged.

By continued exposure to the air mercury absorbs a small quantity of oxygen at ordinary temperatures; but the oxide is mixed or dissolved with a large quantity of mercury, and forms on the surface a grey pellicle which adheres to glass. The oxidation proceeds much more rapidly at the boiling point of mercury. By keeping mercury in a state of slow ebullition in a matrass with a long neck open to the air, the *red oxide* of mercury, formerly called *red precipitate*, is produced under the form of small prismatic crystals.

Two combinations of mercury with oxygen are known. One is the *suboxide* or *black* oxide, Hg_2O, which is not a very stable compound although it forms with acids salts which crystallize readily. It may be obtained by precipitating one of these salts, the nitrate for example, by means of caustic potash: the black precipitate which is formed decomposes spontaneously into red oxide and metallic mercury. By rubbing this black powder in a mortar for some time, metallic mercury is produced: this decomposition is more rapid at the temperature of 212°, or even at the ordinary temperature under the influence of the solar rays.

The *protoxide* or *red oxide* of mercury, HgO, is formed, as already noticed, by exposing the metal to

a high temperature in contact with air. But this plan is very slow in operation, and scanty in results. It may be more abundantly produced by decomposing nitrate of mercury HgO,NO_5, at a heat sufficient to decompose and expel the acid. It may also be obtained by calcining the nitrate of the suboxide Hg_2O,NO_5, but the appearance of the product varies according to the kind of nitrate used. Thus the nitrate of the protoxide in small crystals furnishes a crystalline oxide of mercury of a brick-red colour, and the nitrate of the suboxide gives an oxide of an orange-yellow. By pouring caustic potash into a solution of nitrate of the protoxide of mercury a yellow precipitate of the oxide is formed which is anhydrous. A solution of corrosive sublimate may also be used for this purpose. The red and yellow oxides are isomeric, and in some chemical reactions behave differently. The yellow oxide is more easily attacked by chlorine than the red, and it also combines, at ordinary temperatures, with oxalic acid, which is not the case with the red oxide. The red oxide is slightly soluble in water, to which it imparts an alkaline reaction and a metallic taste; it is very poisonous: it is decomposed by heat, producing metallic mercury and oxygen gas. Indeed, it was by means of this substance that oxygen gas was discovered by Priestley, and that Lavoisier afterwards showed the composition of atmospheric air. The red oxide is sometimes adulterated with red lead; by placing the powder on a red-hot iron, the mercury will be entirely dissipated, but the lead will remain.

It has been already stated that nitric acid acts with facility on mercury, but the action varies with the temperature, and the strength of the acid. When cold and somewhat diluted, salts of the grey oxide are formed, and these are neutral or *basic*, (*i.e.* with excess of oxide,) according as the acid or the metal is in excess. With hot concentrated acid, the mercury is raised to its highest state of oxidation, and a salt of the red oxide is produced. Both classes of salts are liable to be decomposed by a large quantity of water, giving rise to insoluble or sparingly soluble basic compounds. The *neutral subnitrate* of mercury, Hg_2O,NO_5+2HO, is formed by dissolving mercury in an excess of cold dilute nitric acid; it forms large colourless crystals soluble in a small quantity of water without decomposition. With an excess of mercury a finely crystallized basic salt is deposited, containing $3Hg_2O,2NO_5+3HO$, which is also decomposed by water. The two salts may be distinguished when rubbed in a mortar with a little chloride of sodium; the neutral compound gives soda and calomel; the basic salt, nitrate of soda and a black compound of calomel with oxide of mercury. When ammonia is dropped sparingly into a solution of subnitrate, a black substance is produced, called *Hahnemann's soluble mercury.* When red oxide of mercury is dissolved in excess of nitric acid and gently evaporated, a syrupy liquid is obtained, and if the vessel containing it be placed over another vessel containing lime or sulphuric acid, and the whole be covered with a bell jar, voluminous crystals and crystalline crusts will be obtained; their composition is $2HgO,NO_5+HO$. There are other methods of forming this compound, which is decomposed by water into other and more basic compounds. Nitrate of mercury is used in the arts as a wash for rabbit and hare skins: it imparts to their furs the property of felting, which does not naturally belong to them.

Nitrate of mercury is also the source of *fulminating powder*, the mode of preparing which will be given under PERCUSSION CAPS.

When sulphuric acid is added to a solution of the subnitrate of mercury, a *sulphate of the suboxide* Hg_2O,SO_3, is formed: it is a white crystalline powder, only slightly soluble in water. By boiling together equal weights of sulphuric acid and mercury the latter is wholly converted into a heavy white crystalline powder, which is the *sulphate of the protoxide*, HgO,SO_3. The excess of acid may be removed by evaporation. This sulphate is decomposed by water, which dissolves out an acid salt and leaves an insoluble yellow basic compound, formerly called *turpeth* or *turbith mineral.* By long continued washing, the remaining acid is removed, and pure oxide of mercury left.

The compounds of mercury and chlorine are of importance in medicine and the arts. The *subchloride*, or *calomel*, Hg_2Cl, may be, as Fownes remarks, well prepared by pouring a solution of the subnitrate into a large excess of a dilute solution of common salt. It falls as a dense white insoluble precipitate, which must be well washed with boiling distilled water and dried. But the actual method of forming calomel is more complicated. Dry sulphate of the red oxide is rubbed in a mortar with as much metallic mercury as it already contains, and a quantity of common salt, until the globules disappear, and the mixture becomes uniform. This mixture is then sublimed in an alembic, but instead of the usual head to that apparatus, which would collect and condense the calomel into a solid mass, the vapour of the calomel is carried into an atmosphere of steam, or into a chamber containing air, by which means it is condensed in a minutely divided state and the laborious process of pulverising avoided.[1] The reaction is thus explained by Fownes:—

1 equivalent of sulphate of mercury	1 eq. mercury.........	Calomel, Hg_2Cl.
	1 eq. oxygen	
	1 eq. sulphuric acid	
1 equivalent of metallic mercury		
1 equivalent of common salt...........	1 eq. chlorine.........	
	1 eq. sodium.........	Sulphate of soda.

Calomel, when pure, is a heavy, white, insoluble, tasteless powder: in the solid state it phosphoresces when scratched or broken in the dark: it sublimes below a red heat. It is immediately decomposed by an alkali or by lime water and the suboxide produced. It is insoluble in cold dilute nitric acid: but the acid when hot and strong oxidizes and dissolves it. Calomel is apt to contain a little corrosive sublimate, which is dangerous in a substance used so largely in

(1) A patent was taken out by Dr. A. T. Thomson, in 1843, for the manufacture of calomel and corrosive sublimate, by directly combining the vapour of mercury with chlorine.

medicine; it may be detected by boiling in water, filtering and adding caustic potash, when the presence of corrosive sublimate is indicated by a yellow precipitate.

A native chloride of mercury, the *horn quicksilver* of the mineralogist, is found at Almaden in Spain, and also at Moschellandsberg in the Palatinate. It is of a greyish white or yellow colour, and has a conchoidal fracture. At the latter mine it covers the surface of a ferruginous gangue, and in some cases affords a distinct crystal belonging to the right prismatic system. This mineral is occasionally found at Idria and also in Bohemia.

Chloride of mercury, or *Corrosive sublimate*, HgCl, may be obtained by various processes. Its formation is often shown at the lecture table by heating a globule of mercury in a deflagrating spoon and plunging it into a bottle of chlorine; the metal takes fire and produces the chloride. By dissolving the red oxide in hot hydrochloric acid, the chloride crystallizes on cooling. But the usual plan is to sublime a mixture of equal parts of sulphate of the red oxide of mercury and dry common salt. The decomposition is thus given by Fownes:—

1 eq. sulphate of mercury...	1 eq. mercury.........	Corrosive sublimate.
	1 eq. oxygen	
	1 eq. sulphuric acid	
1 eq. common salt	1 eq. chlorine.........	
	1 eq. sodium	Sulphate of soda.

Corrosive sublimate is a white, transparent, crystalline mass of great density; it fuses at 590°, and boils and volatilizes at a somewhat higher temperature. It is soluble in 16 parts of cold and 3 of boiling water: it crystallizes from a hot solution in long white prisms: it is also soluble in alcohol and ether, and the latter will even withdraw it from its aqueous solutions. It combines with other metallic chlorides, forming beautiful double salts. It absorbs ammoniacal gas rapidly. When an excess of solution of ammonia is added to a solution of corrosive sublimate, a white insoluble substance is thrown down named *white precipitate*. Several compounds of chloride of mercury with oxide of mercury are formed by adding an alkaline carbonate or bicarbonate, in varying proportions, to a solution of corrosive sublimate. Corrosive sublimate forms insoluble compounds with many organic substances which contain nitrogen, such as albumen. The great antiseptic virtues of corrosive sublimate may be due to this property: by its means animal and vegetable substances are preserved from dry-rot and decay, as in Kyan's method of preserving timber and cordage. The formation of insoluble compounds with albumen renders white of egg a good antidote to corrosive sublimate in cases of poisoning.

Mercury and iodine unite in two proportions. The *subiodide*, Hg_2I, is formed when a solution of iodide of potassium is added to nitrate of the suboxide of mercury; it separates as a dirty yellow greenish insoluble precipitate. The *iodide*, HgI, is formed by mixing a solution of iodide of potassium with chloride of mercury; the precipitate is at first yellow, but it quickly changes to a brilliant scarlet, which colour is retained on drying. This, which is the neutral iodide, may be procured, but of a duller tint, by triturating single equivalents of iodine and mercury with a little alcohol. The iodide is dimorphous and the colour is red or yellow according to the figure. When the iodide is suddenly heated it becomes bright yellow throughout, and affords a copious sublimate of minute brilliant yellow crystals. If in this state it be touched by a hard body, it instantly becomes red, and this change takes place spontaneously after an interval. By a very slow and careful heating a sublimate of red crystals of a totally different form may be obtained, and these are permanent. An iodide of mercury has been found native in some of the Mexican mines; its colour resembles that of cinnabar, but is deeper.

The compounds of sulphur are important. When 1 part mercury is triturated for some time with 3 of sulphur a black tasteless compound is obtained, which was formerly called *Ethiops mineral*. It is doubtful whether this is a definite sulphuret. The *subsulphuret*, Hg_2S, is formed when sulphuretted hydrogen is passed into a solution of subnitrate of mercury. The black precipitate thus produced is decomposed by heat into metallic mercury and neutral sulphuret. The *sulphuret* of mercury, *artificial cinnabar* or *vermilion*, HgS, is most easily prepared by subliming an intimate mixture of mercury and sulphur. As this substance is of importance in the arts, we will give examples of the various methods of preparing it.[1] When 5 or 6 parts of mercury are added to one part of melting sulphur, and the mixture heated with constant stirring till the sulphur becomes thick, combination takes place suddenly, attended with evolution of light and heat, and with violent crackling and projection of the mass. The resulting compound exhibits a blackish-red colour, and frequently a distinct red streak; it may be regarded as cinnabar partly mixed with black sulphide[2] of mercury, and partly with uncombined mercury and sulphur in a state of minute division. Now, when this crude product, after being pounded, is mixed with a small quantity of sulphur, and a glass flask half filled with it is loosely closed with a charcoal stopper, sunk to two-thirds of its depth in sand, and exposed for some hours to a red heat in a slow-drawing wind-furnace, a sublimate of pure cinnabar is obtained. The excess of sulphur being more volatile than the cinnabar, escapes; foreign metals remain in the form of sulphides at the bottom of the flask. If the upper part of the flask becomes too hot, a portion of the cinnabar may be lost by volatilization. The old method of preparation in Amsterdam is to add gradually 170 pounds of mercury to 50 pounds of melted sulphur contained in a cast-iron pot, the materials being stirred up with an iron spatula, but not so rapidly as to give rise to active combustion—the mixture poured out upon an iron plate, and broken into pieces after cooling,—and the fragments put into hand-jars capable of hold-

(1) These examples are selected from the very full notice of Mercury contained in Gmelin's Chemistry, vol. vi. of the Cavendish Society's Translation, 1852.

(2) The term *sulphide* is now commonly used instead of *sulphuret*.

ing $1\frac{1}{2}$ lb. of water. The subliming vessels are earthen cylinders 4 feet high, glazed within and closed at the bottom; they are sunk to two-thirds of their depth in a furnace in which their lower part is heated to redness. A few hand-jars full of the mixture are thrown into each of these subliming vessels, and the contents left to crackle and burn, till the greater part of the excess of sulphur volatilizes, and the flame diminishes. The smooth level opening is then covered with a thick, smooth plate of cast-iron; the plate removed as soon as a sufficient quantity of cinnabar has collected upon it; the cinnabar which has collected on the upper part of the vessel pushed down again; a fresh plate put on, &c. The contents of the cylinder are stirred up from time to time, and fresh material introduced. The cinnabar, after being detached from the plates, is ground as finely as possible with rain-water.

The method of preparation in Idria is to procure a number of casks, and place in each 8 pounds of pounded sulphur and 42 pounds of mercury. The casks thus charged are made to turn upon their axes for two or three hours, till the contents are converted, with slight evolution of heat, into a brown powder. 100 pounds of this powder are then introduced into an upright cast-iron cylinder, previously heated in a furnace; the cylinder covered with an iron capital, kept down by weights till the crackling of the mass is over; the iron capital thereupon replaced by one of stone-ware, having its beak connected with a tube and receiver, and the fire increased. The best cinnabar collects in the capital, which is afterwards broken in pieces; that which condenses in the tube and receiver, if mixed with excess of sulphur, is added to the quantity introduced at the next sublimation. The cinnabar, after being finely ground with water, is well boiled with potash-ley and washed with boiling and with cold water.

The Chinese method is to sublime 1 part sulphur and 4 parts mercury in an earthen vessel, to which an iron cover, kept constantly moist, is luted; the fire is kept up for 24 hours; the vessel broken up after cooling; the less pure sublimate separated; the purer portion pounded up, and the powder sifted into a large vessel filled with water; the water with the scum floating on it poured off after a while, the process being twice repeated; and lastly, the sediment at the bottom is dried. European cinnabar, whether prepared in the dry or in the humid way, always has a tinge of yellow; the Chinese, which is six times as dear, inclines to carmine colour, although no foreign matter can be detected in it, excepting a little glue. By the sublimation of common cinnabar with 1 per cent. of sulphide of antimony, a dark steel-grey cinnabar is obtained, which becomes brown-red when pulverized; but if it be finely ground, and repeatedly boiled with a solution of liver of sulphur,[1] then thoroughly washed and digested with hydrochloric acid, and afterwards washed and dried, it becomes exactly like the Chinese vermilion, but of a still finer colour. No antimony can be detected in it. The chief point to be attended to in the preparation of cinnabar by sublimation is, that no black amorphous sulphide get mixed with it.

(1) Compounds obtained by fusing potash or its carbonate with sulphur were formerly called *livers of sulphur*, in consequence of their colour.

We will now give an example or two of the method of forming this pigment in the humid way, premising that the black amorphous sulphide of mercury obtained by the action of sulphuretted hydrogen, or of alkaline hydrosulphates, or hydrosulphites, on mercury, its oxides and salts, is converted by contact with alkaline hydrosulphites, slowly in the cold, but quickly when heated, into the red sulphide. Brunner carefully triturates 100 parts of mercury with 38 parts of flowers of sulphur, till the whole is converted into Ethiops—a process which requires 3 hours for small quantities, and 12 hours if the quantity amount to a few pounds—and heats it in a porcelain basin, or a cast-iron pot, with a solution of 25 parts of potash-hydrate in 133 to 150 parts of water, keeping the temperature uniformly at 45°, and never letting it rise above 50°. At first, the mixture is constantly stirred with the pestle, afterwards from time to time. The water which evaporates is replaced, so as not to allow the mixture to acquire the thickness of jelly. When the reddening has once begun, which generally takes place in about 8 hours, the heat must not be allowed to rise above 45°; and as soon as the red has attained its greatest degree of brightness, the vessel is removed from the fire, or else, which is better, the mixture is kept for some hours exposed to a gentler heat. It is then washed, and the mercury which remains metallic, separated by levigation, whereupon it yields from 109 to 110 per cent. of cinnabar, but little inferior to the finest native variety, and far superior to that obtained by sublimation. The above mentioned proportion of the ingredients gives the largest amount of cinnabar. 100 parts of mercury yield, with 40 parts of sulphur and 40 of potash-hydrate, 107 cinnabar; with 28·3 sulphur, and 51 potash-hydrate, 94·2; with 33 to 40 sulphur, and 60 potash-hydrate, 81·5; and with 30 sulphur, and 60 potash-hydrate, only 47·3 cinnabar.

Martius places the ingredients in bottles closed with corks, and packs them in a box, which is fastened to the upper beam of a saw-mill. In 24 or 36 hours, at ordinary temperatures, the most beautiful cinnabar is obtained; it is afterwards washed and dried. This method not only has the advantage of dispensing with the labour of trituration, but it likewise prevents the hitherto unexplained passage of the cinnabar into a brown state, which is so liable to take place on the application of heat.

There are several modes of adulterating vermilion. The substances employed are brick-dust, oxide of iron, red lead, and dragon's-blood. Brick-dust remains behind on ignition, oxide of iron the same: it may also be dissolved out by hydrochloric-acid. Red lead remains behind on ignition in the form of a fused protoxide, and yields chloride of lead with evolution of chlorine on boiling the substance with hydrochloric acid; it may also be extracted by large quantities of

boiling water. Dragon's-blood produces an empyreumatic odour on the application of heat, and also gives a red colour to alcohol.

In concluding this notice of the more important salts of mercury, a few general characters may be stated. The salts of mercury are all volatilized or decomposed by ignition, and the metal produced either by heat alone, or by the addition of a little dry carbonate of soda. The metal is precipitated from its soluble combinations by a plate of copper, and also by a solution of protochloride of tin in excess. Caustic potash and ammonia give characteristic precipitates with the chloride and soluble salts of the red oxide.

Mercury dissolves many of the metals with facility, forming what are termed *amalgams*. [See AMALGAM.] It is this property which renders mercury so valuable in extracting gold and silver from their ores, and also in the operations of gilding [see BUTTON], plating, and the manufacture of looking-glasses, the silvering of which, by amalgam of tin, is described under GLASS, Section VIII. An amalgam of silver is employed for stopping hollow teeth.

We come now to notice the treatment of the ores of mercury. Mercury is found native in fluid globules disseminated through the gangue, and sometimes accumulated in cavities, so that it can be dipped up. The only ore of mercury, properly so called, is the sulphuret: it has a dull red colour, and leaves a bright scarlet streak. It is mostly found in connexion with talcose and argillaceous shale, or in some other stratified deposit, usually in the form of veins or lodes; but when the matrix is sandstone, it is disseminated in minute grains throughout the mass.

The chief mines which yield mercury are at Idria in Austria, Almaden in Spain, in the Palatinate on the Rhine, and in Peru. The metal has also been found in Hungary, Sweden, China, Japan, Mexico, and Chili. At Idria, the sulphuret is worked in a formation composed of a compact black limestone associated with an argillaceous schist. The rock is too friable to admit of large excavations, so that the workings are carried on by means of small galleries. The ore is chiefly bituminous cinnabar associated with native mercury, and it is obtained at a depth of 850 feet from the surface. Native mercury is sometimes so abundant that when the ground is first broken it escapes in large globules which collect in the bottoms of the levels. The pure metal is separated by filtration from earthy matters, which are mechanically treated previous to roasting. The mines of Almaden were known to the Greeks 700 B.C., and Pliny mentions them as yielding a large supply of mercury. The vein varies from 14 to 16 yards in thickness: a black slate, impregnated with metallic mercury, is also worked. The mines do not exceed 300 yards in depth; they are excavated in argillaceous schist and sandstone grit deposited in horizontal beds, which in some places have been intersected by eruptions of granite and black porphyry. The mines of the Palatinate are of less extent than the Austrian and Spanish mines, but like them, the government either works them on its own account or farms them to private speculators. The workings are numerous, and are situated in various geological positions. The mines of Hungary, Bohemia, and other parts of Germany, are of small extent, not producing collectively more than from 35 to 40 tons of mercury per annum. The produce of the Peruvian mines has hitherto been chiefly employed in treating the ores of gold and silver.

In the treatment of the ores of mercury for the purpose of extracting the metal, we will first notice the plan adopted at Idria. The ores are divided into two classes according to the size of the lumps, which in the first class vary from the size of a nut to a cubic foot, and in the second, from the size of a nut to the finest dust. The ores in the first class admit of three divisions, viz. the poorest species, which yield only 1 per cent. of mercury; the massive sulphuret with the richest picked pieces, often containing 80 per cent. of metal; and, lastly, the splinters arising from the picking and sorting of the different ores, and which yield from 1 to 40 per cent. There are also three varieties in the second class, viz. small fragments from the mine, which average from 10 to 12 per cent. of metal; pieces of ore separated by washing on a sieve, and containing 32 per cent. of metal; and lastly, the fine sand and paste, called *schlich*, obtained by stamping and washing the poorer ores: this yields about 8 per cent.

These various forms of the mineral are subjected to a high temperature in a distillatory apparatus. The sulphur burns away as sulphurous acid gas, and the mercury thus set free distils over, and condenses in chambers prepared for the purpose. The kiln and condensing chambers are represented in sectional elevation and plan in the following figures. They form together probably the largest metallurgic erection in the world, the length being 180 feet, and the height 30 feet. The ore, in large fragments, is piled upon the vault *v*, Fig. 1428, which is pierced with a number

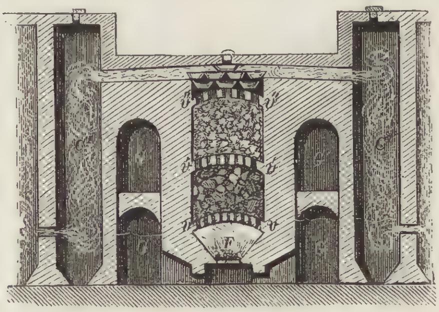
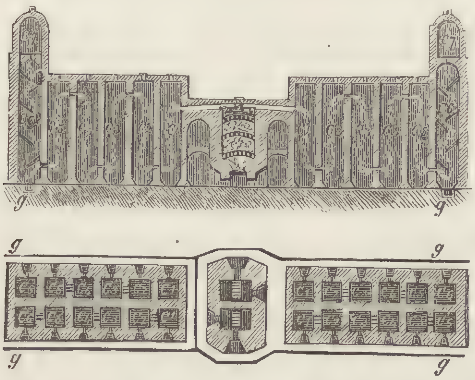


Fig. 1428. MERCURY SUBLIMING FURNACE AT IDRIA.

of openings, and the space above it is completely filled. Smaller fragments are piled on the second vault *v*′, and upon the third vault *v*″ is piled a number of earthen pans containing the dust of the ore and the slich. These pans are also used in the space above *v*′ *v*′ should the ore be very small. The furnace being thus charged, a fire is kindled in the hearth F, and the temperature is gradually raised. The sulphuret of mercury is exposed to the constant action of numerous currents of air, which pour into the spaces

above $v\ v'$ through a number of small holes made through the sides of the furnace, and opening into the galleries G G′. As the ore is decomposed under the oxidising action of the air, the mercurial vapours



Figs. 1429, 1430. ROASTING KILN AND CONDENSING CHAMBERS AT IDRIA.

escape into the condensing chambers $c^1\ c^2$, &c. Most of the mercury condenses in the first three chambers, whence it flows by gutters $g\ g'$ into a covered reservoir below the level of the floor. In the other chambers $c^4\ c^5$, a large quantity of water and very little mercury are condensed, and as this mercury is mixed with a good deal of dust, it is collected by separate gutters, and is afterwards purified by filtration, the residue being returned to the furnace at a subsequent charge. Whatever vapour of mercury escapes into the last chamber c^6, is condensed by means of a current of water falling down inclined planes, which project from the walls, as shown in Fig. 1429, and whatever vapour and gas escapes this action is then discharged into the air. The mercury is filtered through thick linen bags, and then packed in wrought-iron bottles for exportation.

The kiln is charged in 3 hours by the united labour of 40 men. Beechwood is usually employed as fuel, and the distillation lasts from 10 to 12 hours, during which the furnace is kept at a cherry-red heat. A full charge for the double apparatus requires from 1,000 to 1,200 quintals of ore, which produce from 80 to 90 quintals of metallic mercury. The furnace takes 5 or 6 days to cool, so that allowing time for charging and withdrawing the residue, only one distillation can be made in the course of the week. This furnace was erected in 1794, previous to which an aludelle furnace, next to be described, was employed.

The march of improvement is more slow paced in Spain than in Austria, so that in the former country the old *buytrone* or *aludelle* furnace still continues to be used. It is more imperfect in its action, and consequently more injurious to the health of the people employed, than the Idrian arrangement. It consists of a circular or polygonal chamber, C C′, Fig. 1431, divided into two compartments by a brick vault v furnished with apertures. The ore is piled up on the vault, first in large fragments, then in smaller ones, and the whole is covered with soft bricks formed of clay, the finer parts of the ore, and the disintegrated residue of previous operations. At the upper part of C′, are openings o, which communicate with a number of adapters or pipes fitting into each other, so as to form a long channel upon the terrace T. These adapters are called *aludelles*, and are represented on a larger scale in Fig. 1433. They

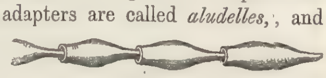
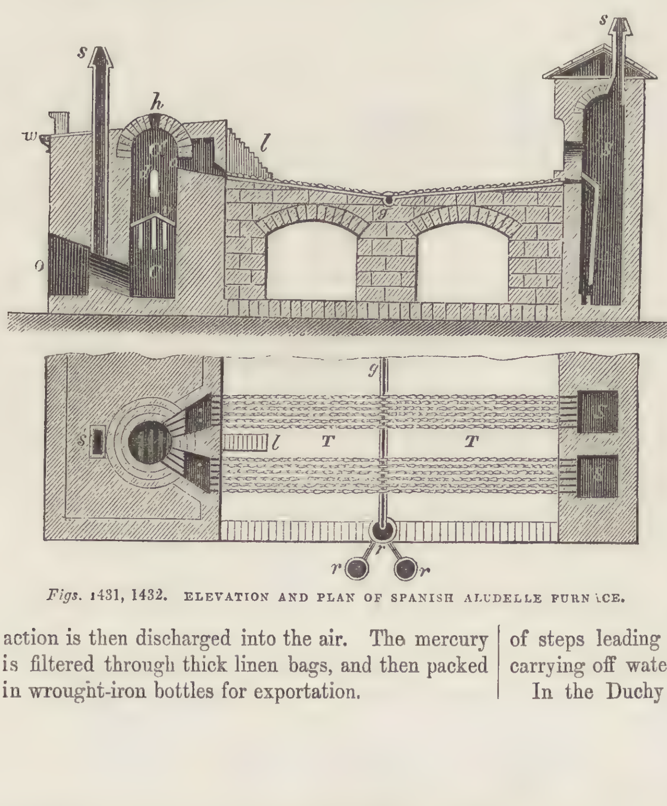


Fig. 1433.

are thrust into each other, and luted at the joints with softened loam. The mercury condenses in the aludelles, and a portion remains there, but the larger portion escapes by a hole pierced in the under part of the lowest of the series, and escapes by the gutter g into the reservoirs $r\ r$. The gas mingled with the uncondensed mercurial vapour passes into the shaft S, and accumulates on the walls in the form of mercurial soot, which is swept down from time to time, filtered to separate metallic mercury, and what is left is kneaded into the bricks which are used to cover the top of the charge. The fuel, which usually consists of brushwood, is introduced by the opening O into C, the smoke escaping by s. The fire is kept up for 12 or 13 hours, after which the kiln is left for 3 or 4 days to cool. The kiln is then cleared out, and a fresh charge introduced through the door d. l is a flight of steps leading to the furnace, and w a pipe for carrying off water.



Figs. 1431, 1432. ELEVATION AND PLAN OF SPANISH ALUDELLE FURNACE.

In the Duchy of Deux-Ponts, in the Palatinate,

the ore, which is of a mixture of cinnabar and calcareous rock, is roasted in a kind of earthern retort R, Fig. 1434, to the mouth of which is luted an earthern receiver *r*, containing water. The retorts are arranged in a gallery furnace in the side walls of which openings are left for the necks of the retorts; and the receivers are arranged on shelves outside. In this case the sulphuret of mercury is decomposed by the lime, with the formation of sulphuret of calcium and sulphate of lime, and the liberated mercury condenses in the receivers. Pit coal is the fuel used.

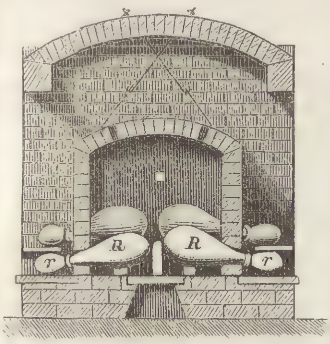


Fig. 1434. FURNACE USED IN THE PALATINATE.

About the year 1847, a form of apparatus closely resembling that used in the manufacture of gas from bituminous coal, [see GAS] was erected under the superintendence of Dr. Ure at Landsberg in the Bavarian Rheinkreis. It consisted of a series of retorts *r*, Fig. 1435, set in masonry, and fitted at one

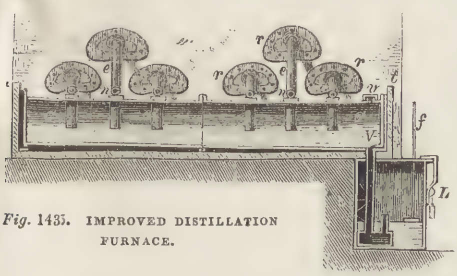


Fig. 1435. IMPROVED DISTILLATION FURNACE.

end with an eduction tube *e*, and at the other with an air-tight stopper kept in place by an iron screw. The eduction pipes are each furnished with a nozzle *n*, closed by a screw plug, and used for introducing a wire to clear away any obstruction arising from adhering mercurial soot. The pipes *e* pass into a large cast-iron condenser C, 18 inches in diameter, filled with water to *w*, a little above the level of the pipes: there is also a water valve *v*, by which any danger of explosion from the rising of the water into the retorts is prevented, and the temperature is further reduced by placing the condenser in a large wooden trough *t*, through which cold water constantly flows The cylinder C slightly inclines towards V, so that the condensed mercury flows along the bottom of the cylinder, and passing down the vertical pipe V, is collected in the iron chest B, which is secured by a lock at *l*. At the commencement of the operation, the tube V is closed at bottom by dipping into a shallow iron cup filled with mercury, and as the mercury accumulates the amount of increase is indicated by the graduated iron float *f*. The retorts are kept constantly and uniformly ignited, so that the injury to the joints arising from contraction and expansion by alternate cooling and heating, is avoided. Each retort will contain a charge of ore weighing 5 cwt., and the metal is almost entirely dispelled from it in 3 hours.

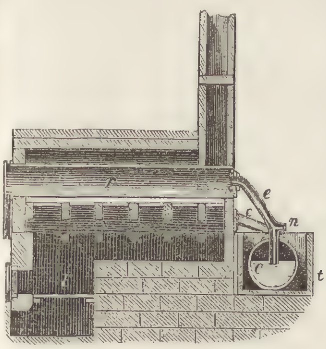


Fig. 1436. SIDE ELEVATION.

In the year ending 5 January, 1851, the quantity of mercury imported into the United Kingdom amounted to 355,079 lbs. In the previous year the quantity was 2,229,458 lbs.

METAL. In the list of elementary substances given under ATOMIC THEORY (vol. i. p. 91), the metals are by far the most numerous, and their importance in the useful arts is equal to their extent. They are diffused very unequally through the earth's crust; some are rare, others extremely abundant; some are of most importance in the metallic state, others when in combination with oxygen, &c. Their properties are so numerous that we must refer to them under their respective heads for their uses and applications, and direct our attention in the present article to those more general properties which belong, more or less, to all the metals, or to considerable groups of the metals.

There are, however, certain points in which all metals agree: they all have *metallic lustre*, they are all *good conductors* of heat and electricity, and they are all *electro-positive* or *cations;* that is, when a metallic compound is decomposed by the electric current, the metal is given off at the cathode, or negative pole, or electrode.

The most striking property of metals is their *lustre*, which serves to distinguish them from the non-metallic elements, carbon, boron, phosphorus, sulphur, selenium, and iodine. This lustre is evident, whether the metals be in masses or in small fragments, and even when in the finest dust it can be made evident by means of an agate burnisher. This lustre seems to depend on the *opacity* of metals, and on the facility with which they take a polish, more or less perfect: hence they are eminently adapted to reflect light, since their opacity prevents the transmission and their polish the absorption of the luminous rays. There are, however, a few exceptions to the perfect opacity of the metals; for gold leaf transmits green rays, and the alloy of gold and silver also, in the form of leaf, transmits blue rays.

With respect to the *colours* of metals, copper and titanium are red; bismuth is pinkish, and gold is yellow. All the other metals present a certain degree of uniformity, from the pure white of silver to the bluish-grey tint of lead.

Metals differ so much in their *densities*, that while potassium is lighter than water, platinum is nearly 21 times heavier than an equal bulk of that fluid. The specific gravities of the more common metals, at the temperature of 60°, are as follows:—

Platinum	20·98	Iron	7·79
Gold	19·26	Molybdenum	7·40
Tungsten	17·60	Tin	7·29
Mercury	13·57	Zinc	6·86 to 7·10
Palladium	11·30 to 11·80	Manganese	6·85
Lead	11·35	Antimony	6·70
Silver	10·47	Tellurium	6·11
Bismuth	9·82	Arsenic	5·88
Uranium	9·00	Titanium	5·30
Copper	8·89	Aluminum	2·60
Cadmium	8·60	Magnesium	1·70
Cobalt	8·54	Sodium	0·972
Nickel	8·28	Potassium	0·865

With respect to *hardness*, the metals offer differences as striking as those which relate to their density; for while some are very hard, others can be scratched with the thumb nail, or even moulded between the fingers. The following table shows the relative degrees of hardness of the more common metals:—

Titanium, Manganese	Harder than steel.	Nickel, Cobalt, Iron, Antimony, Zinc	Scratched by glass.
Platinum, Palladium, Copper, Gold, Silver, Tellurium, Bismuth, Cadmium, Tin	Scratched by calc spar.	Lead	Scratched by the nail.
		Potassium, Sodium	Soft as wax at 60°.
		Mercury	Liquid at ordinary temperatures.
Chromium, Rhodium	Scratch glass.		

All the metals have the property of assuming the crystalline form, but it is not always easy to place them under circumstances favourable to their doing so. Many of them occur in nature in what is called the *native* state, in a crystalline form, particularly gold, silver, copper, and bismuth. Some metals crystallize when reduced to the fluid state by heat, and allowed to cool slowly. When a solid crust has formed on the surface, if the fluid metal be poured out from within (as described under Bismuth, Fig. 136), the interior crust will be found lined with crystals. Crystals of antimony, lead, and tin may be obtained in this way, but not so readily as in the case of bismuth, larger masses of metal and slower cooling being required. In iron foundries, crystals of that metal are sometimes found in the midst of large masses which have been allowed to cool slowly. Some metals are also precipitated in a crystalline form from solutions of their salts by means of another metal. A strip of zinc in a solution of acetate of lead precipitates the lead in feathery crystals: silver is deposited by mercury; and gold by a stick of phosphorus in an ethereal solution. Electric currents of feeble intensity produce crystals from solutions of the metals; and it is probable that owing to this action in the earth's crust many of the metals are found in a native crystalline form. The most common crystalline form of metals is the regular octahedron, or the cube. Antimony, however, crystallizes in rhombohedrons.

Metals are often valuable in the arts on account of their *malleability* and *ductility*, by which they admit of being flattened by the hammer or the rolling-mill into leaves or plates, or drawn out into wires. The metals, however, possess these properties very unequally, and some not at all; for on striking them with a hammer they fly into fragments. Such metals are termed *brittle*. The rolling-mill consists of two metallic cylinders, Fig. 1437, placed one above the other, mounted in suitable bearings, with adjustments for increasing or diminishing the distance between them. The metal to be rolled is cast into the form of an ingot, of nearly the same width as the required plate: one end of the ingot is made wedge-shaped, in order to enter easily between the rollers and be caught by their grip: the ingot is then dragged through by their motion, diminished in thickness and increased in length. The operation is repeated many times, the rollers being gradually brought nearer together, until a sheet of almost any required tenacity is produced. Some metals can be rolled cold, others require to be previously heated. During the rolling, however, the molecular constitution of the metal becomes modified, and its malleability diminished; it becomes hard, brittle, and difficult to work; it is then said to be *rash*, and it requires to be *annealed*, that is, raised to a high temperature, and allowed to cool gradually down to the temperature at which it is worked, before the lamination can be proceeded with. [See Annealing.] In the following list the metals are arranged in the order of their malleability:—

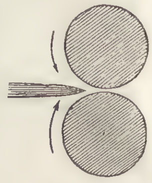


Fig. 1437.

Gold.	Platinum.	Palladium.
Silver.	Lead.	Potassium.
Copper.	Zinc.	Sodium.
Tin.	Iron.	Frozen Mercury.
Cadmium.	Nickel.	

The malleability of gold is such that a grain can be made to cover a surface of 54 square inches, and that leaf-gold is $\frac{1}{250000}$th of an inch in thickness. [See Gold.]

The *ductility* of metals does not follow the order of their malleability; as for example:—

Gold.	Nickel.	Lead.
Silver.	Copper.	Palladium.
Platinum.	Zinc.	Cadmium.
Iron.	Tin.	

The ductility of metals depends upon their *tenacity*, or power of resisting the tension applied to them in forcing them through the holes of a *draw-plate*, which is an oblong piece of steel, Fig. 1438, with trumpet-shaped holes gradually diminishing in size. The metal is first formed into a rod; the extremity is then pointed and dragged through the largest hole; then through the next smaller size, and so on gradually decreasing in diameter; but between these operations the metal requires to be annealed as in the case of the rolling-mill. By

Fig. 1438.

this means silver can be drawn into wires $\frac{1}{500}$th of an inch in diameter, and by enveloping an ingot of gold with silver previous to drawing, a grain of gold may be drawn into a wire 550 feet long: this wire is covered with silver, which may be washed off by putting it into dilute nitric acid, and the resulting gold wire is only $\frac{1}{5000}$th inch in diameter. Platinum has been substituted for gold; and a wire not exceeding $\frac{1}{30000}$th inch in diameter has been produced. Very fine steel wires have been formed by first enveloping the steel in silver, and, after the drawing, dissolving off the silver by means of mercury. [See WIRE-DRAWING.]

Fig. 1439.

The *tenacity* of metals is the power which they possess of resisting tension without breaking. It varies with different metals, and a comparative estimate may be formed by suspending from a fixed point different wires of equal length and diameter by one extremity, and attaching a scale-pan to the other extremity, as shown in Fig. 1439. Weights are successively and carefully added to the scale-pan until the wire breaks, and the number of pounds, &c. represents its tenacity as compared with other wires tested under similar circumstances. The following weights were sustained by wires 0·787 of a line in diameter:—

Iron	549·250 lbs.	Gold	150·753 lbs.
Copper	302·278 „	Zinc	109·540 „
Platinum	274·320 „	Tin	34·630 „
Silver	187·137 „	Lead	27·621 „

The tenacity of metals varies greatly in the same metal with its purity and the method by which it has been wrought. The tenacity is much diminished by the process of annealing. A wire of soft iron which sustained a weight of 26 lbs. only sustained 12 lbs. after being annealed; and one of copper, which sustained 22 lbs. before annealing, was broken by 9 lbs. after being annealed. In fact, the process of annealing had removed the particles to a greater distance from each other, than the rolling-mill or the draw-plate had condensed them.

The following metals are *brittle:* most of them may be reduced to powder:—

Antimony.	Cobalt.	Titanium.
Arsenic.	Columbium.	Tungsten.
Bismuth.	Manganese.	Uranium.
Cerium.	Molybdenum.	Rhodium.
Chromium.	Tellurium.	

Metals vary greatly in their *conducting* powers for heat, as shown by the following table, the numbers representing merely an approximative ratio:—

Gold	200	Zinc	73
Silver	195	Tin	64
Copper	180	Lead	36
Iron	75		

Those metals which transmit heat with the greatest facility are best adapted to the manufacture of steam-boilers, stove-pipes, and other forms of apparatus where it is of importance for the heated surfaces to part with their heat quickly to surrounding bodies.

Metals vary greatly in their *capacity* for heat, or their *specific heat:* that is, the amount of heat required to raise equal weights of the different metals to the same temperature. If the quantity of heat required to raise 1 lb. of water from 32° to 212° be expressed by 1·000, the amount of heat required to raise 1 lb. weight of each of the following metals is expressed by the decimal numbers opposite to each:—

Gold	0·0324	Tin	0·0560
Silver	0·0570	Zinc	0·0929
Platinum	0·0324	Cadmium	0·0567
Palladium	0·0593	Antimony	0·0508
Iridium	0·0368	Bismuth	0·0270
Mercury	0·0318	Arsenic	0·0814
Copper	0·0950	Manganese	0 1441
Nickel	0·1086	Uranium	0·0619
Cobalt	0·1172	Molybdenum	0·0659
Iron	0·1132	Tungsten	0·0364
Lead	0·0320		

The linear *expansion* of a few of the metals on being raised from 32° to 212° has them thus stated:—

Gold	0·00155155 = $\frac{1}{661}$st.
Silver	0·00190868 = $\frac{1}{524}$th.
Platinum	0·00099180 = $\frac{1}{1008}$th.
Palladium	0·00100000 = $\frac{1}{1000}$th.
Copper	0·00171733 = $\frac{1}{582}$d.
Iron	0·00123504 = $\frac{1}{812}$th.
Lead	0·00284836 = $\frac{1}{351}$st.
Tin (from Malacca)	0·00193765 = $\frac{1}{516}$th.
Zinc (Cast)	0·00294167 = $\frac{1}{340}$th.
Zinc (Hammered)	0·00310833 = $\frac{1}{322}$d.
Bismuth	0·00139167 = $\frac{1}{719}$th.
Antimony	0·00108333 = $\frac{1}{923}$d.

Fusibility. All the metals admit of being fused by the application of heat, but the temperatures at which they liquify are very various. At higher temperatures than are required for fusion the metals are volatile, and many of them may be distilled in close vessels. Some metals acquire a pasty or adhesive state before becoming fluid: such is the case with iron and platinum, and also with the metals of the alkalies. In consequence of this valuable property pieces of iron and steel can be united without solder by the process of *welding*, and the finely divided metallic sponge of platinum converted into a solid and compact bar. In the following table, the metals are arranged in the order of their fusibility:—

		Fahr.
Fusible below a red-heat.	Mercury	− 39°
	Potassium	+ 136
	Sodium	190
	Tin	442
	Cadmium	450
	Bismuth	497
	Lead	612
	Tellurium is rather less fusible than lead.	
	Arsenic volatilizes before it fuses.	
	Zinc	773
	Antimony fuses a little below redness.	
Infusible below a red-heat.	Silver	1873
	Copper	1996
	Gold	2016
	Cobalt is rather less fusible than iron.	
	Iron, cast	2786
	Iron, malleable; Manganese — Require the highest heat of a smith's forge.	
	Nickel, nearly the same as cobalt.	
	Palladium; Molybdenum; Uranium; Tungsten; Chromium; Titanium; Cerium; Osmium; Iridium; Rhodium; Platinum; Columbium — Almost infusible, and not to be procured in buttons by the heat of a smith's forge; but fusible before the oxyhydrogen blow-pipe.	

Many of the metals (copper, iron, and tin, more especially) if slightly elevated in temperature by friction, or otherwise, emit a remarkable *odour*, and if applied to the tongue impart a metallic *taste*.

The harder metals are *elastic* and *sonorous*, but these properties are more conspicuous in some of the alloys than in the pure metals.

Metals form certain combinations with each other which are termed *alloys* [see ALLOY], or if mercury be one of the combining metals, *amalgams* [see AMALGAM]. In these cases the distinctive characters of metals are retained; but in the compounds formed by the union of a metal with the non-metallic elements, forming what are called *oxides*, *chlorides*, *sulphides*, &c., the metallic character most frequently disappears.

The affinities of the different metals for oxygen vary greatly. Some of the metals combine with it at all temperatures, and are reduced with difficulty; others, on the contrary, cannot be made to combine directly with it, and their oxides are decomposed at a slight increase of temperature. These different affinities of the metals for oxygen may be estimated in various ways. 1. By their behaviour with oxygen gas or common air at different temperatures. 2. By the greater or less facility with which their oxides are reduced to the metallic state. 3. By their power of decomposing water under varying circumstances. 4. By their power of decomposing water acidulated by one of the stronger acids: as when water is acidulated by sulphuric acid, iron or zinc decompose it at ordinary temperatures with the evolution of hydrogen gas. [See HYDROGEN.] Other metals do not produce this effect even at high temperatures. The decomposition, however, is influenced by the affinity of the resulting oxide for the acid, and also by the degree of solubility of the salt produced.

According to these views Regnault[1] arranges the metals into six groups, which show at a glance their most striking characteristics. In the first group are those metals which absorb oxygen at all temperatures, even the most elevated, and of decomposing water at the lowest, hydrogen gas being abundantly evolved. These metals are—

Potassium.	Lithium.	Strontium.
Sodium.	Barium.	Calcium.

The first three are called *alkaline metals:* the last three are the metallic radicals of the *alkaline earths.*

In the *second* group are placed those metals which absorb oxygen at the highest temperatures, and whose oxides are not reduced by heat alone: these metals do not sensibly decompose water at low temperatures, but they do so decidedly above 122°. They are—

Manganese.	Magnesium.	Aluminum.

To which the following may also probably be added—

Glucinum.	Thorium.	Didymium.
Zirconium.	Cerium.	Erbium.
Yttrium.	Lanthanum.	Terbium.

The *third* group comprehends metals which decompose water at a red-heat, whose oxides are not reduced by heat alone, and which do not decompose water below 212°; but they all decompose water at ordinary temperatures when acidulated by the stronger acids. They are—

Iron.	Chromium.	Cadmium.
Nickel.	Vanadium.	Uranium.
Cobalt.	Zinc.	

The temperature at which these metals decompose water and absorb oxygen depends greatly upon their state of division. Iron, in the state of filings, does not absorb oxygen rapidly at ordinary temperatures: if heated to dull redness in oxygen gas the action is so rapid as to produce heat and light: if the metal be very minutely divided, it will take fire by mere exposure to the air. [See IRON.] Iron filings decompose steam at 450°.

In the *fourth* group are those metals which absorb oxygen at a red-heat, and hence cannot be reduced to the metallic state by heat alone; they decompose steam with great facility, but not water acidulated by the stronger acids. The reason is that the oxides of these metals afford but feeble bases, while most of them in the presence of the stronger bases, such as potash and soda, behave as acids. Thus most of the following metals decompose water in the presence of the alkalies with the production of hydrogen gas:—

Tungsten.	Tantalum.	Tin.
Molybdenum.	Titanium.	Antimony.
Osmium.		

And probably,

Niobium.	Ilmenium.	Pelopium.

In the *fifth* group are metals which absorb oxygen at a red-heat, and whose oxides are not reducible by heat alone: they decompose water at very high temperatures, but only in a feeble manner: they do not decompose water in the presence of acids or alkalies. They are—

Copper.	Lead.	Bismuth.

In the *sixth* group are metals whose oxides are reducible by heat alone. They are—

Mercury.	Iridium.	Ruthenium.
Silver.	Palladium.	Gold.
Rhodium.	Platinum.	

All the metals whose oxides are not decomposed by heat alone can decompose water at temperatures more or less elevated. This arises from the fact that water is resolved into its elements at very high temperatures, and when an oxidisable metal is present, the latter unites with the oxygen to form an oxide, and the hydrogen escapes in the gaseous form.

The metallic oxides vary greatly in their properties. Some of them possess basic characters more or less marked; others will not combine either with acids or with alkalies; while a third set have distinct acid properties. The strong bases are all protoxides, containing single equivalents of metal and oxygen: the weaker bases are usually sesquioxides, containing 2 equivalents of metal, and 3 of oxygen: the peroxides, or neutral compounds, contain still more oxygen; and lastly, the metallic acids contain the largest quantity of oxygen. The gradual change in properties by the

(1) Cours de Chimie, tome 2e.

increasing proportions of oxygen may be illustrated by taking manganese as an example :—

	Metal.	*Oxygen.*	*Symbols.*	*Characters.*
Protoxide	1 eq.	1 eq.	MnO.	Strongly basic.
Deutoxide	2 eq.	3 eq.	Mn_2O_3.	Feebly basic.
Peroxide..................	1 eq.	2 eq.	MnO_2.	Neutral.
Manganic acid	1 eq.	3 eq.	MnO_3.	Strongly acid.
Hypermanganic acid .	2 eq.	7 eq.	Mn_2O_7.	Strongly acid.

A powerful oxygen acid and a powerful metallic base uniting in such proportions as exactly to neutralize each other's properties, form what is called a *neutral salt;* it produces no effect on litmus or turmeric paper. In neutral salts there is a constant relation between the quantity of oxygen in the base and the quantity of acid in the salt, which is thus expressed :—To form a neutral combination, as many equivalents of *acid* must be present in the salt as there are of *oxygen* in the base. Mr. Fownes thus explains the application of this law :—" When a base is a protoxide, a single equivalent of acid suffices to neutralize it; when a sesquioxide, not less than three are required. Hence, if by any chance the base of a salt should pass by oxidation from the one state to the other, the acid will be insufficient in quantity by one half to form a neutral combination. Protosulphate of iron offers an example: when a solution of this substance is exposed to the air, it absorbs oxygen, and a yellow insoluble *sub-salt* is produced, which contains an excess of base. 4 equivalents of the green compound absorb from the air 2 equivalents of oxygen, and give rise to 1 equivalent neutral and 1 equivalent basic persulphate, as indicated by the diagonal zig-zag line of division :—

1 eq. iron + 1 eq. oxygen .... 1 eq. sulphuric acid.
1 eq. iron + 1 eq. oxygen .... 1 eq. sulphuric acid.
+ 1 eq. oxygen from the air.
1 eq. iron + 1 eq. oxygen .... 1 eq. sulphuric acid.
1 eq. iron + 1 eq. oxygen .... 1 eq. sulphuric acid.
+ 1 eq. oxygen from the air.

Such subsalts are very frequently insoluble."

Chlorine, iodine, bromine, and fluorine, combine with the metals and form compounds, which possess a highly saline character. But if a salt be a compound of an acid and a base, the chlorides, iodides, &c. are certainly not salts, and even common table-salt (*chloride of sodium*, or, as it was formerly termed, *muriate of soda*), which gives the name to the numerous family of salts, has no relationship therewith. To get rid of the difficulty of excluding bodies which partake so largely of the saline character, if not in constitution, at least in properties, two classes of salts have been formed; the first, named *haloid* salts (from ἅλς, sea-salt, and εἶδος, form), includes those constituted after the type of common salt, containing a metal and a salt-radical, as chlorine, iodine, &c.; and the second, named *oxygen-acid*, or *oxy-salts*, includes those salts which are generally represented as being composed of an acid and an oxide, such as sulphate of soda, nitrate of potash, &c.

The old term, mûriate of soda, was applied to culinary salt on the supposition that muriatic acid combined with soda to form such a salt; but according to the more modern and probably correct view, when a solution of a hydrogen acid, such as muriatic, now called *hydrochloric* acid, is poured upon a metallic oxide, both are decomposed, and water and a haloid salt of the metal produced. In the case of hydrochloric acid and soda for example :—

Hydrochloric acid .... { Chlorine...... → Chloride of Sodium.
{ Hydrogen ...
Soda .... { Sodium ......
{ Oxygen ...... → Water.

On evaporating the solution crystals of chloride of sodium are obtained.

The properties of the two great classes of salts are, however, so very similar that attempts have been made to constitute them alike. Thus we may regard oxy-salts not as compounds of an oxide and an acid, but as containing a metal in union with a compound salt radical having the chemical relations of chlorine and iodine. Thus sulphate and nitrate of potash will be constituted in the same manner as chloride of sodium, the compound radical replacing the simple one. Hence, instead of representing sulphate of potash by $KO+SO_3$ it will be $K+SO_4$, and nitrate of potash instead of being $KO+NO_5$ will be $K+NO_6$. Hydrated sulphuric acid will be, like hydrochloric acid, a hydruret of salt-radical $H+SO_4$. When the latter acts upon metallic zinc, the hydrogen is simply displaced and the metal substituted, no decomposition of water being supposed to take place. When the acid is poured upon a metallic oxide the same reaction occurs as in the case of hydrochloric acid, water and a haloid salt are produced. All acids are therefore hydrogen acids, and all salts haloid salts, with either simple or compound radicals. This *binary theory of salts*, as it is called, was originally suggested by Sir H. Davy.

Sulphur combines with all the metals leading to the production of *sulphurets* or *sulphides*. Many of them have a saline character, and are soluble in water, such as the sulphuret of potassium and of sodium. Two sulphurets will in some cases unite in definite proportions and form a crystallizable compound. Such bodies resemble oxygen-acid salts; " they usually contain a monosulphuret of an alkaline metal, and a higher sulphuret of a non-metallic substance, or of a metal which has little tendency to form a basic oxide, the two sulphurets having exactly the same relation to each other as the oxide and acid of an ordinary salt. Hence the expressions *sulphur salt, sulphur acid*, and *sulphur base;* they contain sulphur in the place of oxygen. Thus bisulphuret of carbon is a sulphur acid: it forms a crystallizable compound with simple sulphuret of potassium, which is a sulphur base. Were oxygen substituted for the sulphur in this product we should have carbonate of potash. $KS+CS_2$ is the sulphur salt, and $KO+CO_2$ the oxygen salt."

Two different bases are sometimes united with the same acid, forming what are called *double salts*. Thus sulphate of copper and sulphate of potash mixed in the ratio of their equivalents, dissolved in water and evaporated, a double salt, viz. sulphate of potash and copper, is obtained. Those salts called *super* or *acid salts*, such as bisulphate of potash, which have a sour taste, and an acid reaction to test paper, are by some

chemists regarded as double salts, in which one of the bases is *water*. "Strange as it may at first sight appear," says Fownes, "water possesses considerable basic powers, although it is unable to mask acid reaction on vegetable colours; hydrogen, in fact, very much resembles a metal in its chemical relations. Bisulphate of potash will, therefore, be a double sulphate of potash and water, while oil of vitriol must be assimilated to neutral sulphate of potash. $KO+SO_3$ and $HO+SO_3$." Water is a weak base: it is for the most part easily displaced by a metallic oxide, but occasionally it decomposes a salt in virtue of its basic power. A few acid salts contain no water: bichromate of potash for example. Such a salt may be constituted with 2 equivalents of acid to 1 of base.

For further remarks on the constitution of salts we must refer to CRYSTALLIZATION, and a few other articles. The principal metallic salts are noticed under the names of the metals as they are separately treated of.

METALLURGY is the art of extracting metals from their ores: it depends on certain mechanical and chemical operations, the object of the former being to separate much bulky worthless material, in order that the chemical processes may be performed with advantage on the residual metallic portion. By the mechanical processes, the mineral is separated from its gangue (quartz, felspar, limestone, barytes, &c.), and by the chemical, the metal is smelted or disentangled from its mineralizer (sulphur, arsenic, phosphorus, &c.) A special chemical treatment is, in general, required for each metal, and will be found described each under its own heading. The mechanical processes are of a more general nature; but their extent must depend, in great measure, upon the commercial value of the metal, and the facility with which its ores can be dressed and afterwards smelted. The ores of iron would not repay the cost of mechanical preparation, in consequence of their abundance, the ease with which they are reduced, and the consequent low price of the metal. The ores of copper admit of a good deal of preparatory dressing, on account of the higher commercial value of that metal.

Fig. 1440. BREAKING AND SORTING COPPER ORES.

The first dressing of the ores is usually performed by the miner: he separates the larger fragments of the gangue, and sends up only such a description of ore as will pay the cost of the labour to be bestowed upon it. On reaching the surface the ores are sorted by women and children, and broken up by means of hammers into, 1, fragments rich enough to be sent at once to the calciner or to the smelter; 2, into pieces composed of the mineral mixed with the gangue, and which require dressing; 3, into fragments of the gangue, which are rejected. The fragments in the second class are crushed by means of large cylinders of cast-iron, and after passing between these, the crushed mineral falls into the upper extremity of an inclined cylinder of coarse wire gauze, which, moving upon its axis, separates the pulverised mineral into two classes: the one passing through the meshes falls on the floor; the other, consisting of fragments too large to pass through, falls out at the lower extremity of the cylinder into an endless chain of buckets, by which it is raised to the level of the mill to be crushed over again. Ores of copper are treated in this way. The *crushing machine* used at Alston Moor for breaking the mingled ores of lead is represented in the steel engraving. It consists of one pair of fluted cylinders $f\,f'$, and 2 pairs of smooth cylinders c c, which are all used for crushing the ore. They are turned in opposite directions by means of toothed wheels $t\ t'\ t''$, working into each other, and fixed to the shafts of one of each of the 3 pairs of cylinders. Motion is given by a water-wheel w w, to the axis of which is attached one of the fluted cylinders f'. The axis of the water-wheel also carries a cast-iron toothed wheel t, geered with the toothed wheels $t'\ t''$, fixed upon the ends of two of the smooth cylinders. Above the fluted cylinders is a hopper H, which discharges between them the ore, as it is brought by the waggons W. These waggons advance upon a railway, and as each gets over the hopper, its motion is arrested, and a trap-hole opening outward in the middle of the bottom is let fall, and the waggon discharges its contents into the hopper. Below the hopper is a small bucket called a *shoe*, into which the

Fig. 4

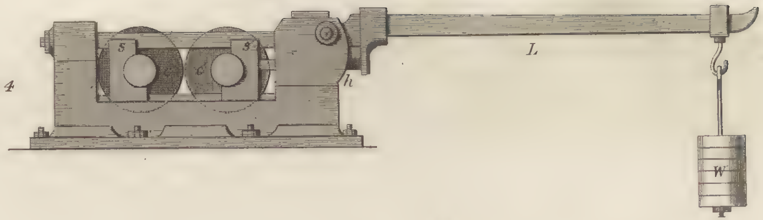


Fig. 3

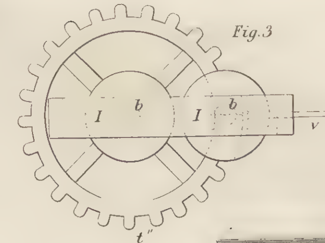


Fig. 2

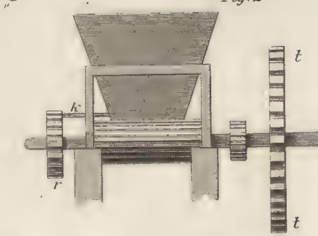
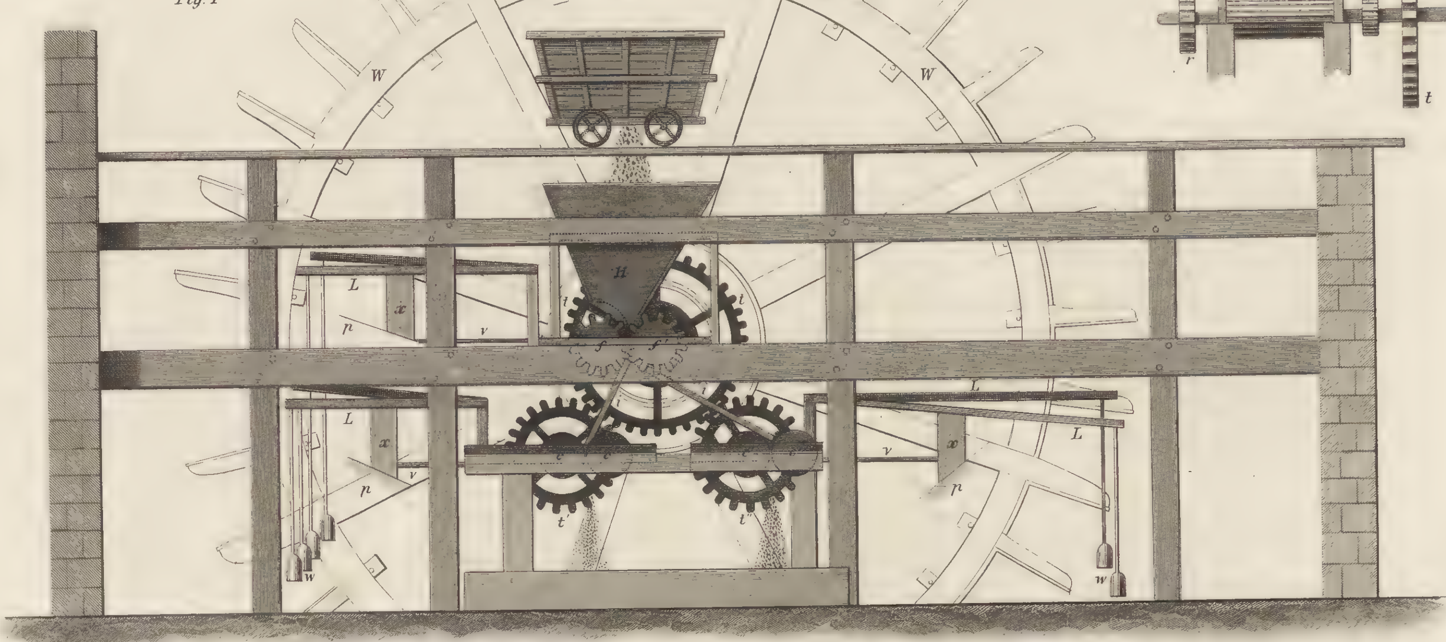


Fig. 1



MILL FOR CRUSHING ORES

ore is shaken down, and which throws it constantly upon the cylinders in consequence of a jolting motion given to it by a crank rod *k*, Fig. 2, attached to it, and kept vibrating by the teeth of the wheel *r*. The shoe is regulated in such a manner as to prevent too much ore falling on the cylinders and obstructing their motion. A small stream of water is also let into the shoe for the purpose of preventing the cylinders from heating. The ore is first passed between the fluted rollers, then falls upon the inclined planes *i i*, which turn it over to one or other of the pairs of smooth rolls. These are the chief parts of the machine: they are made of iron, and the smooth rolls are case-hardened, or chilled. [See CASE-HARDENING — ANNEALING.] The gudgeons of the cylinders move in brass bushes (*b*, Fig. 3) fixed upon iron supports, I, made fast by bolts to the massive wood-work supports of the machine.

Each of the horizontal bars has an oblong slot, at one end of which is solidly fixed one of the plummer blocks, or bearers of one of the cylinders *c'*, and in the rest of the slot the plummer block of the other cylinder *c* slides. This construction permits the 2 cylinders to approach each other so as to be in contact, or to recede from each other as circumstances may require. The movable cylinder is driven up nearer to the fixed one by means of iron levers L L, which carry at their ends the weights *w*, and rest upon wedges *x x*, which can be made to slide on inclined planes *p p*. In such cases these wedges press upon the iron bar *v*, Figs. 1 and 3, and urge it nearer the movable cylinder by advancing the plummer block which supports its axis. The effect of this arrangement is, that if a very large and hard piece of ore get between a pair of cylinders, one of them would yield and allow the piece to pass without injuring the mechanism. This object may be attained by a more compact arrangement, as shown in Fig. 4. The bearings *s s'* of the rollers *c c* slide in grooves, and the shoulder *h* of the loaded lever L, pressing up against the bearing *s'* constantly tends to keep the surfaces of the two cylinders in contact: the weight W is adjusted so as to suit the hardness of the mineral to be broken. In addition to the 3 pairs of rollers of which each crushing machine consists, a fourth pair is sometimes added for crushing the moderately rich and poorer pieces of lead ore known as *chats* and *cuttings*, produced by the first sifting of the brake sieve. These cylinders are smooth, and are known as *chats-rollers*. One of them is usually placed on the prolongation of the shaft of the water-wheel on the side opposite to the principal machine, and the other, which is placed alongside, receives its motion from the first by toothed wheel-work. When the gangue is too hard to yield to the rollers, and for those ores which require to be ground more finely than is done by rolling, a *stamp-mill* is used.

Many minerals, such as tin, are pounded into small fragments by means of large pestles, in an arrangement called a *stamping-mill*, which will be described presently. The ores are then concentrated by a variety of operations similar in principle, but varying greatly in detail. This principle ought to be clearly understood before the operations themselves are described, and as it has been very clearly explained by Regnault, in the third volume of his "Cours de Chimie," we give an abstract of it in this place:—

If bodies differing in form, magnitude, and density be allowed to fall from a considerable height into a tranquil liquid, they will evidently experience different degrees of resistance in finding their way to the bottom, so that they will not all reach it at the same time; but will arrange themselves in a certain order, which it is of importance to the metallurgist to be able to determine. If these bodies have the same form and dimensions, and differ only in density, it follows, since the resistance which a body experiences in moving through a liquid depends on its form and the extent of its surfaces, and not upon its density, that all these bodies will lose an equal amount of moving force in passing through the liquid. But this loss will be most felt by bodies which have a less degree of velocity, such as bodies of less specific gravity. They will fall more slowly through the liquid than the denser bodies, and arriving last of all at the end of their course, will be found resting on the denser bodies in a graduated order, the most dense being at the bottom, the least dense at the top of the solid strata.

If the bodies which fall through the liquid are of similar density and form, spheres or cubes, for example, but of varying magnitudes, their velocity will be in proportion to their size, and the largest fragments will form the lowest stratum at the bottom of the vessel. The bodies being alike in density and form, the resistance in falling through the liquid is proportional to the surface exposed; and as the volumes of bodies vary according to the cube of their corresponding dimensions, while the surfaces only vary with the square, it follows that the velocity of descent which animates them is regulated by their cubes, d^3, while their resistance is in proportion to their squares d^2: hence the descending force of a body increases much more rapidly than the resistance offered by its surfaces.

If, lastly, we suppose all the bodies to have the same volume and density, but to vary in form, some being cubical and others in the form of flat rectangular laminæ, or scales; the latter, having a much greater extent of surface than the cubes, experience a much greater amount of resistance in falling through the liquid: the cubes will arrive first at the bottom, and upon them will be deposited the plates or scales, and if these are more or less flattened, the flattest will occupy the highest stratum.

Now, to apply these principles to the dressing of ores. We have seen that the ores are first broken up and separated into distinct classes, each of which comprises fragments of about the same size. Let us suppose that these fragments consist, some of pure mineral, some of gangue only, others of mineral and gangue mixed, but that all have the same form and the same volume. As the metalliferous part is usually much denser than the gangue, it is evident that in falling through water from a considerable height, the

mineral would arrive first at the bottom, and would be followed by fragments composed of mineral and gangue, and the pieces of pure gangue would arrive last. The mixture would thus be formed into three portions; gangue at the top, which could be separated and thrown away; pure mineral at the bottom, which could also be separated, and sent to the calciner or to the smelter; while the intermediate portion would have to be again crushed, sifted, &c. to get rid of more of the gangue. Hence it will be seen how important it is that the fragments of the ore which are to be concentrated by washing, should be nearly of the same size and form. This, however, is not always possible. It is comparatively easy to reduce the fragments to the same size, but their forms must, to a great extent, depend on the molecular constitution of the mineral and gangue, and on their natural cleavages, &c. Hence it is very likely that among the crushed fragments of an ore, all of which have passed through the same riddle, there may be found lamellar pieces of the metallic mineral, and cubical or spherical pieces of the gangue. The mineral, by its superior density, would tend to pass more quickly through the water than the gangue; but the latter, in consequence of its form, may experience less resistance than the lamellar fragments of the metallic compound; and hence the two bodies may arrange themselves according to the inverse order of their densities. Cases of this kind constantly occur in practice, and hence the results are not so precise as they would otherwise be if the conditions upon which the theory is based could be realized. Of course, the more nearly these conditions can be realized, the more perfect will be the purification of the ore by washing.

As a tolerably complete illustration of the mechanical preparation of ores, we will give a full abstract of Mr. Henwood's valuable paper on the methods adopted in Cornwall for dressing tin ores.[1] It may, however, be necessary first to state, that tin ores are generally carried through all the operations necessary for their purification previous to being smelted. The smelter has, therefore, only to carry them twice through the furnace: by the first melting they are brought into a metallic state; and by the second, the metal is sufficiently purified. The ores of copper, on the contrary, are only brought by the miner into the state which makes them fit for roasting or calcining: in this state they are sold to the smelter, who passes them through the long series of operations described under Copper, before the metal is fit for the market. On this account, although a given quantity of average copper ore, as it comes from the lode, is much richer and more valuable than an equal quantity of tin ore in the same state, the tin ore, when prepared for sale, is at least seven times richer than that of the copper.

(1) This paper is printed among the "Transactions of the Royal Geological Society of Cornwall." The engravings are from original drawings made on the spot by Mr. F. B. Miller, of King's College, London, for the purpose of illustrating a treatise in the Editor's work on the Useful Arts, &c. published under the sanction of the Committee of General Literature and Education appointed by the Society for Promoting Christian Knowledge.

The tin of the Cornish mines is nearly all in the state of peroxide, of variable purity; it is sometimes crystalline, and at others mingled with much earthy matter. When raised from the mine, the first operation is to break in pieces, about as large as a man's fist, any pieces of ore, or *stones* as they are called, that may exceed that size, and to reject such portions as do not contain more ore than will repay the cost of dressing. In some stones the tin ore is scarcely perceptible to the eye; in which case the workman from time to time reduces a small quantity to a fine powder, and by repeatedly immersing it in water, and shaking it to and fro on a shovel, the impurities are removed: by this simple operation, which is called *vanning*, the quality of the ore is roughly ascertained, as well as the size to which it must be reduced in order to free it from foreign substances.

The ore is now ready for the *stamping-mill*. This consists of a number of upright wooden beams called *stampers*, about ten feet long and eight inches square, to the lower extremities of which are attached pieces of cast iron, varying in weight from one hundred and a-half to four hundredweight and a-quarter. These are placed in a wooden frame, and alternately lifted up about ten inches by the cogs or wipers of a horizontal axle, which is moved round either by a water-wheel or a steam-engine. [See D *d* of the steel engraving.] Where the latter power is used, the number of stampers is increased to 24, 36, and even 48. The ore is placed on an inclined plane close to the bottom of the stampers, and as these are lifted up, a portion of it slides down directly beneath them and is crushed by their fall. The aperture through which it is admitted, is of such a size as to prevent the entrance of so much as would impede the action of the machine. The second stamper is lifted an instant before the fall of the first, and the third before that of the second. The fall of the first forces a portion of the ore beneath the second, and that of the second beneath the third: the fall of the last forces such of the ore as has been sufficiently pulverised through a copper or iron grating, placed opposite the aperture by which the ore is admitted under the stamper. The holes of the grating vary in size according to the nature of the ore, from the diameter of a reed to that of a small needle. The whole arrangement is copiously supplied with water, which assists the progress of the tin through the grating. Adjoining the stamping-mill, and connected with the grating by a conduit, are two pits: the ore after passing through the grating runs into the nearest pit, in which the rough ore lodges, as well as the heavier part of that which has been reduced to powder, and known by the name of *slime;* this rough ore when dressed is called the *crop*. The remainder, with the lighter slime, which, passing through the first pit, is retained in the second, when dressed, is called the *leavings*, and varies in quantity from one-fourth to one-seventh of the whole. Now begins the process of purification, so far as to prepare the ore for being smelted; and this comprises a large number and variety of operations, but the great principle of

the whole is that of subsidence by the superior weight of the metallic portion, as compared with the stony and earthy matters which are to be got rid of.

The first operation on the crop is called *buddling*. The buddle is a wooden case about 8 feet long, 3 wide, and $2\frac{1}{2}$ feet deep, fixed in the ground, one end being a little elevated; on the rim of the higher end is fixed a board, called the *jagging-board*, from 12 to 16 inches wide, extending from side to side, and somewhat more inclined than the buddle. The opera-

Fig. 1441. BUDDLING.

tor, who may be a man or a woman, spreads the ore on the jagging-board, and with a shovel cuts it into small furrows parallel to the length of the buddle: a small current of water, which is admitted at the head of the buddle, is made to flow equally on every part of the board. The quantity of water is regulated by the roughness of the ore; the coarsest requires about as much as a circular aperture, $1\frac{1}{2}$ inch in diameter, would admit; but the finest only about one-ninth of that quantity. The action of the water carries all the ore into the case, where the richer and finer portions subside near the head, while the rougher and lighter portions are carried towards the lower part. The workman, who stands in the buddle, or on a plank over it, about 3 feet from the head, assists the action by gently passing the foot, or a tool held in the hand, along from side to side. When the ore is rough, this operation is sometimes performed with the naked foot; but when the particles are very fine, the foot is usually shod with a smooth piece of wood called the *brogue*. This process is continued until the buddle is full. Its contents are then divided into three or four parts, according to the quality of the ore; the richest part, termed *heads*, is near the head of the buddle; the *tails*, or worst part, being near the foot; the intermediate portions are called *first* and *second middle heads*. These are again separately buddled, until the ore at the head is freed from the poorer and rough particles. The *heads* are then *tossed* or *tozed* in a kieve or large tub, about one-third filled with water, which one workman stirs about rapidly while another gently puts in the ore with a shovel. The tub is furnished with a stirrer, the construction of which will be seen in Figs. 1442, 1443. The stirring is continued till the vessel is nearly

Fig. 1442. TOSSING, OR TOZING.

full: it is then stopped, and the outside of the kieve is struck smartly with a hammer until the ore has subsided: this is called *packing*. By this process the most impure parts are brought to the top, whilst the remainder subsides in the order of its weight. The whole is now divided horizontally into two or more parts, the lowest division being fit for smelting, unless it is found to require roasting, in order to get rid of the ores of iron, copper, and zinc, which is often the case. The upper division, called *skimpings* (skimmings), are again buddled and tossed; the tails are thrown amongst the *leavings*, and the ore in the lowest part of the kieve is again fit for the smelting or the calcining-house.

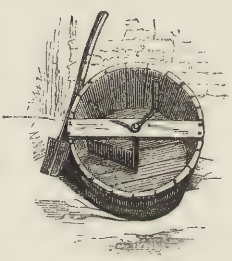


Fig. 1443. THE KIEVE.

The first middle heads are also subjected to an operation termed *chimming*, which is similar to tossing. The kieve in which it is performed is inclined at an angle of about 45°. About 2 cwt. of ore, with an equal weight of water, are put into it, and violently agitated by stirring until the whole of the ore is suspended: the vessel is then beaten on the outside as in tossing; the water being withdrawn, the upper layers of ore, also called skimpings, are treated in the same way as after tossing: the lower part is fit for the smelting or calcining-house. This plan may be substituted for tossing both for heads and middle heads, especially when the impure parts of the ore are very heavy. When the kieve is inclined, the space at the bottom is narrower, while the space near the surface of the water is larger and the depth greater than if it were horizontal, as in tossing. Mr. Henwood thinks it probable that the impure parts are thus more easily kept in suspension, and from the greater vibrating motion imparted by the hammering, in consequence of the kieve resting on a small and narrow

base, the whole of the richest part may subside more speedily than it does in tossing.

The second middle heads are generally subjected to the operation of *dilluing.* It is performed with a hair-bottomed sieve of close texture, into which an assistant puts about 30 pounds of ore: the operator then immerses it in a kieve about two-thirds full of water, and by moving it round, as well as up and down, and from side to side in the water, the small and light particles become suspended, and by inclining the sieve, they pass out of it and subside at the bottom of the kieve:[1] the sieve is regularly replenished from the ore-heap by the assistant, and the operation is continued. Whether the ore in the sieve is now fit for the smelting-house, is ascertained by the process of *vanning,* already described; but if not sufficiently pure, the next operation, supposing it does not require to be roasted, is *tying;* but as most of the tin ore of Cornwall requires roasting, this operation is the next part of the process.

The object of roasting is to get rid of ores of copper, iron, or zinc, mixed with the tin ore. The furnace in which the ore is *burnt,* as the miners call it, is a common reverberatory furnace: it is raised to a dull red heat, and then about 7 cwt. of the ore is put into it through a hole in the top. It is allowed to remain for about an hour, to get rid of the moisture imbibed in the previous processes, and is then spread over the furnace, for about 4 feet in length, nearest the fire, and by means of an iron rake is turned about every half hour, that the whole may be equally exposed to the action of the fire. This is continued until the ore ceases to give out whitish fumes, or, when turned, to exhibit bright sparkles; it is then withdrawn through a hole, now uncovered in the bottom of the furnace, and allowed to cool. It is then *sifted,* and after being again tossed, buddled, and again tossed, it is ready for the smelter.

In some cases, however, when the ore is only partially roasted, it is taken out of the furnace and sifted and buddled, and then tossed, chimmed, or dillued: then roasted a second time. In this way some ores are more easily cleansed from their impurities than if they had been wholly roasted at once. The ore in this half-roasted state is called *rag-burnt;* when it has been buddled, the tails are considered equal to the middle heads of the ore, which has not been roasted, and are accordingly tossed, chimmed, or dillued. The skimpings of the tossed ore being again buddled, the tails are thrown by as *burnt leavings,* and as they frequently contain copper, they are sold as copper ore, if the copper amount to 2½ per cent.

When the tin ores are mixed with those of copper (generally the sulphuret) after roasting, the water in which they are sifted holds sulphate of copper in solution. The salt may be obtained by evaporation, or the copper precipitated by the immersion of iron plates into the solution.

(1) The ore which subsides in the bottom of the dilluing vessel, is termed *flying,* or *dilluing smalls,* and is again buddled and tossed, or chimmed, with the middle heads of the skimpings: the produce thus obtained is termed *round* or *leap* ore, and is of the most inferior description.

But some kinds of ore, after being roasted, require *tying.* The *tye* is a long narrow inclined furrow, through which passes a stream of water, three or four times more copious than that used for buddling. The ore being placed at the head, is agitated with a broom, (or with a shovel when the tails of the buddles are

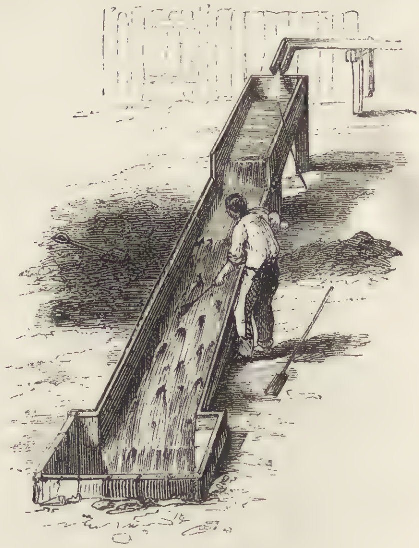


Fig. 1444. TYING.

tyed,) and the rough and lighter particles are carried to the lower part of the tye. The ore at the head, unless it requires to be again dillued, is fit for the smelting-house. The remainder, if very poor, is thrown among the leavings; but if otherwise, it is exposed to another operation called *jigging.*

This is performed by plunging a copper-bottomed sieve, containing two or three shovelfulls of ore, into a vessel of water. The operator, holding the sieve in his hand, gives it both a vertical and rotatory

Fig. 1445. JIGGING.

motion, taking care that it be never lifted above the surface of the water; by this means the different parts arrange themselves in the sieve in the order of gravity; the lighter portions, being brought to the top, are scraped off and considered as *leavings,* and a fresh supply of ore is thrown in and jigged, until the weight of the richer part, at the bottom of the sieve, becomes too great for the operator; it is then taken out in a state fit for smelting. The *jigging-machine* is sometimes used in this operation, but more

commonly in the dressing of copper and lead ores. Its construction is very simple, and will be understood by reference to the annexed engraving, Fig. 1446.

The foregoing operations apply to the *crop;* the *leavings*, consisting of the *slime*, the *tails* of the buddles, the *skimmings* of the skimpings, and the *skimpings* of the jigging, are subjected to a series of operations known as *trunking*, *framing*, or *racking*. Previous to trunking, a large surface of the slime ore is generally exposed to the air to get rid of moisture: it is better if it be thoroughly dried, as the alternations of dryness and moisture facilitate the separation of the soft and earthy substances.

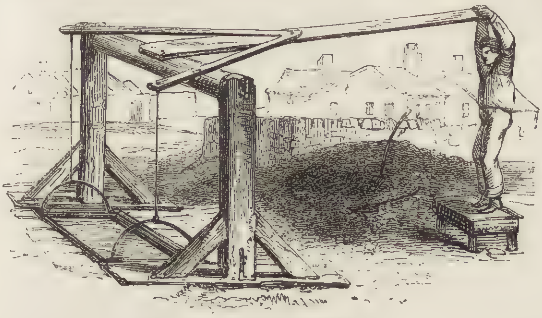


Fig. 1446. JIGGING MACHINE.

The *trunk* consists of three divisions, viz. the *strèke*, the *còver*, and the *hutch*. The strèke is a furrow, about 5 feet long and $2\frac{1}{2}$ feet deep: at the higher end it is $2\frac{1}{2}$ feet wide; but it becomes gradually narrower, so that at the lower extremity it is only 6 inches: it is walled on each side. The còver, which is situated at the lower end of the strèke, is a box of about 3 cubic feet in capacity. The hutch, which is separated by a single plank, is a wooden case about 8 feet long, $2\frac{1}{2}$ to 3 feet wide, and about a foot in depth: its bottom, as well as that of the strèke, is a little inclined. The slime being put into the strèke, a stream of water as large as a circular aperture of $\frac{3}{8}$ths inch in diameter will admit, runs over it, and being occasionally agitated, a portion of the slime is suspended by the water, and is thereby carried into the còver. Too much slime must not be suspended at once: the best proportion is about $\frac{1}{8}$th or $\frac{1}{6}$th of the weight of the water. The operator, usually a child, agitates the water in the còver with a shovel, and causes it to ripple over the dividing plank into the hutch. The quantity passing over at once is very minute, but the ripples succeed each other rapidly, and by this means the best parts of the slime remain at or near the head of the hutch, while the poorer parts are carried off by the water. When the hutch is full, the contents are removed to the *frame* or *rack*. The poorer parts of the slime, termed *loobs*, may be worth a second trunking, which is not often the case if the first operation be well performed; and it is well performed if the liquid in the còver have an equal velocity at the middle and sides. Trunking is often performed by machinery.

The next operation is *framing*, or *racking*, Fig. 1447. The *frame* table is about 8 feet long and 5 feet wide, with a rim 5 inches high round it. This is suspended in an inclined position on pivots, but is fastened by a kind of latch; at the upper end is a jagging-board, similar to that of the buddle, which is connected with a frame by a movable sloping piece of wood, to prevent the ore from falling between the board and the frame; below the frame are two boxes, which, being placed end to end, extend its whole length: at the lower end of the floor a vacancy of two or three inches leaves an aperture for the escape of water. The operator spreads on the jagging-board from 2 to 3 quarts of the *slime* obtained in the previous operation of *trunking*, and with a small toothless rake makes in it small furrows, in the direction in which a stream of water runs, which is let in upon the jagging-board. By this means the ore is carried from the board to the frame; the richest part rests at and near the head, and the poorer parts further down; the impurities are carried off by the water, and escape at the bottom. The operator runs the rake across the frame to agitate the ore, and when the richer part has sufficiently accumulated, the jagging-board being swept clean, the latch is lifted, and the frame turned on the pivots from a horizontal to a vertical position, and the ore is swept or washed into the boxes beneath, the best into the upper, and the inferior into the lower box. It is of importance that the water should pass

Fig. 1447. FRAMING OR RACKING.

of equal depth and velocity over every part of the frame, or the different parts of the mass will be mixed with each other, and some of the ore be carried off with the waste. If the ore deposited in the upper box be contaminated with the ores of copper, iron, or zinc, it is roasted, and afterwards treated the same as that which has not been burnt; viz. it is sifted and tossed: the lower part of the contents of the tossing kieve is buddled, and again tossed, and it is then fit for the smelting-house: the upper part is again framed with a smaller stream of water. The ore deposited in the lower box beneath the frame, may be again framed

with a fresh proportion of trunked ore; but it may be tossed, and the richer contents of the tossing kieve buddled. The ore at the head of the buddle, if not requiring a repetition of the process, is tossed, and is then fit for the smelting-house. The remainder is again trunked, &c.

Fig. 1448 represents the tools used at the racks or frames: *a* is the *scraper*, *b* the broom, and *c* a horn, for rubbing or washing the table.

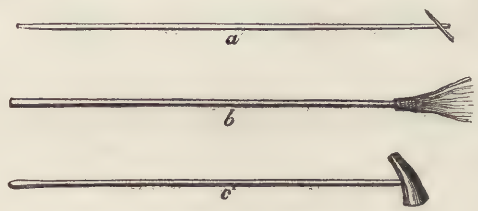


Fig. 1448.

Very little improvement has been made in the mode of dressing tin ores for nearly a century; but of late years, improved machinery has been introduced at some mines.

Lead Ore.—When the lead ore is raised to the surface, it is sorted out into three parcels, called *knockings*, *riddlings*, and *fell*, the last-named being that which passes through an inch iron-wire sieve, in which the riddlings remain; the knockings are the larger pieces of spar or stone, with ore intermixed. The dressing of the ore does not differ in principle from that already described for tin; it is, however, much less elaborate, and many of the processes are called by different names. The buddling is carried on with the water of a running stream, which frequently has the effect of poisoning it. [See Lead.]

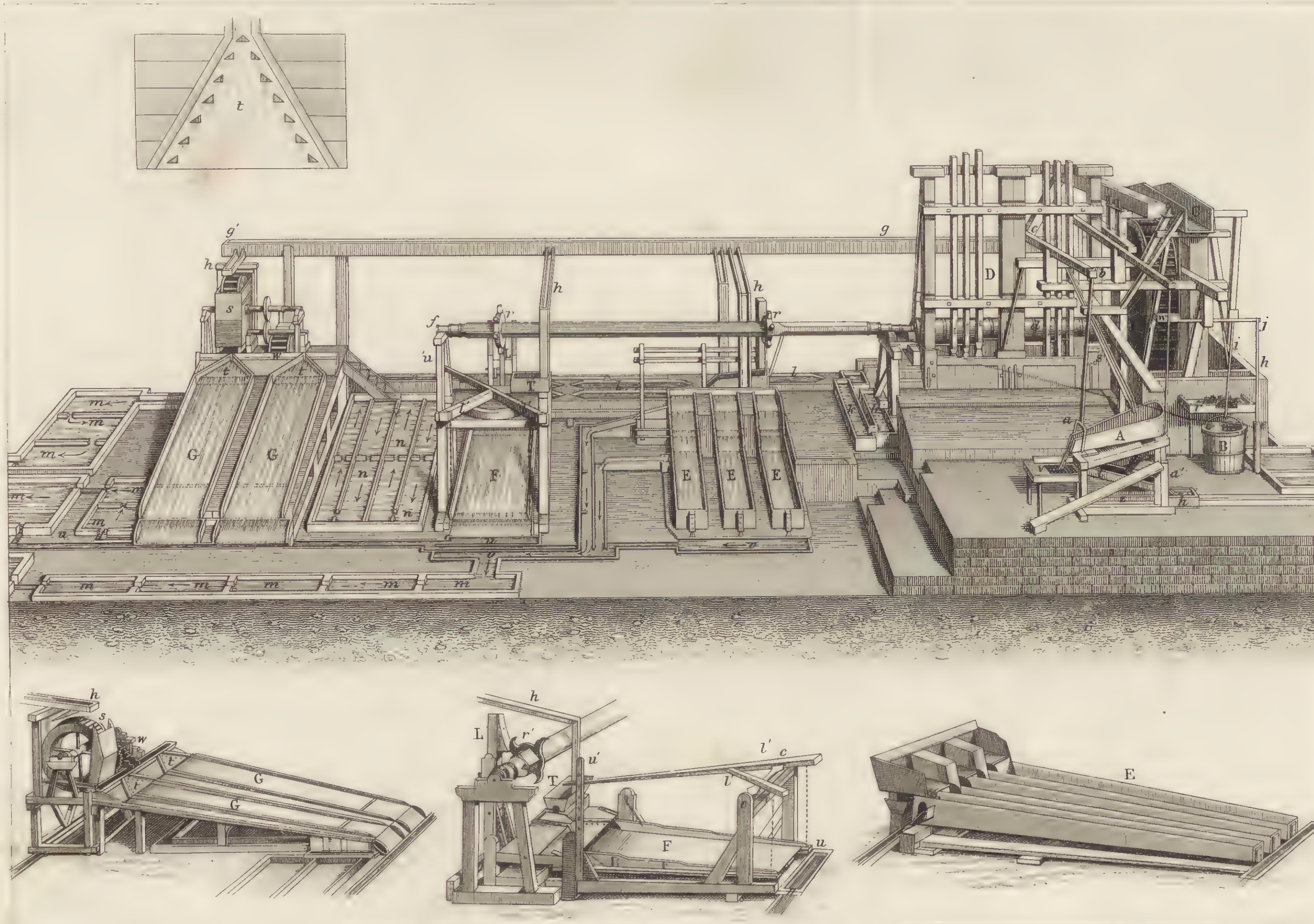
The foregoing details will give a sufficient idea to the general reader, of the methods adopted in this country for concentrating ores by mechanical means. Our steel engraving represents at one view the apparatus used on the Continent for the same purpose: w is an overshot water-wheel, which gives motion to the different machines; the end of the canal which supplies the water being shown at c. The prolonged axis, *d*, of this wheel, is furnished with a number of cogs or wipers, which raise the stamps of the stamp-mill, d. Here the ore is broken up into larger fragments, schlich, and slime ores; the stream of water which supplies the stamps passes into the basins, *k k*, where the heavier fragments are deposited; the water then flows into the canals, *l l*, and thence into the canals, *n n*, where it meanders in the direction of the arrows, and in the course of this long transit gradually deposits the mineral matters suspended in it, the lighter and poorer particles being deposited last.

The washing of the ores is performed on the Continent chiefly by means of three different kinds of apparatus, viz. *percussion sieves* and *tables*, a and f; the *German chest*, e e, and *sleeping-tables*, g g. For the purpose of separating the crushed or stamped ore into fragments of the same size, the percussion sieve (*crible à secousses*), a, is used. This apparatus consists of two troughs or boxes, a and *t* placed one above the other, and set in motion by means of the two rods, *a b* and *a′ b′*, which derive their jerking motion from the wipers on the drum, *d*, acting upon uprights, to which the rods are attached by horizontal connecting pieces. Water is conveyed into the trough, a, by means of a shoot, *s;* a portion of this water passes into the lower trough, *t*, by means of the small shoot, *x*. The bottom of each trough is formed of meshes of iron wire, or of a strong metallic netting; but the meshes are coarser in the box, a, than in the box, *t*. The ore is thrown by means of a shovel into the top of the box, a, and the jerking motion imparted to it by the rod, *a b*, causes the ore to descend upon the grating; one portion passes through the meshes into the lower trough, *t*, where it undergoes a second jigging. The ore is thus divided into three sizes: first, those fragments which are too coarse to pass through the meshes of the box, a, fall upon the table, *v;* secondly, those fragments which pass through the meshes of a, but cannot pass through those of the box, *t;* these fall into the box, *h;* and, thirdly, the fragments which pass through *t*, are collected in a box, *z*, situated immediately below it.

The hand-sieves, which are still used in Cornwall, are almost superseded on the Continent by the simple arrangement shown at b: the mineral to be washed is placed on a table, *r;* b is a large tub of water, in which the sieve, *p*, is suspended by the iron rod, *i;* the proper motion is given to the sieve by moving the rod, *h*, up and down in the tube, *e;* the rod, *h*, is hinged to the horizontal beam, *j w*, to which also the rod, *i*, is attached, and at the extremity, *w*, of the beam, is a box filled with small stones, for counterpoising the weight of the sieve and the rod, *h*.

A somewhat similar apparatus was formerly employed in Cornwall for washing the crushed copper ores; but a more effective arrangement is now in use. This consists of a large box, covered with a tight wooden floor, in the centre of which is a circular metallic trough, perforated with six holes, each about 2 feet in diameter, and into each of these openings a sieve is closely fitted. In the centre of this arrangement is a cylinder in which a piston works, and by its motion alternately elevates and depresses the level of the water in the box, and consequently also in the sieves. By this motion of the water, the particles of mineral contained in the sieves are arranged according to their several densities, and when one sieve is removed for the purpose of scraping off the less valuable and lighter portions of its contents, its place is supplied by another kept ready filled for the purpose.

The German chest (*caisse à tombeau*), e e, is a coffin-shaped box placed in a slightly inclined position, at the lower end of which is a series of holes closed by wooden pegs. At the upper end is a kind of raised platform on which the ore to be washed is placed, and in this a small stream of water is allowed to play; consequently, the finer portions of the mineral are carried off in suspension in the water, and deposited at various distances from the head, depending on their density. When the body of the chest is full of water, the stream is stopped at the head, and one of



the pegs at the lower end being taken out, the water and the lighter particles which it holds in suspension are drawn off into reservoirs, where the solid matter is allowed to subside. As the chest becomes gradually filled a higher peg is removed, and when the pit is quite full the top peg only is taken out. The deposited ore is divided into three classes; the first, and heaviest, near the head of the pit, consists of mineral so far concentrated as to be often fit for smelting: the second and third portions, which are much less rich, are washed over again in the chest, or are transferred to the percussion-table or to the sleeping-table.

The percussion-table (*table à secousses*), F, consists of a wooden flooring attached to heavy wooden sleepers, and suspended by four chains or jointed iron rods: two of the chains near the head are attached to a fixed wooden framework, and two others to a long forked lever *l′ l′*, moving on centres *c c*, and capable of being raised or depressed by a pin placed in the holes of the upright *u′*; this allows the inclination of the table F to be varied, so as to suit ores of different degrees of fineness. The axle *r f*, set in motion by the water-wheel W, is furnished with cams, *r′*, which act on a wooden lever, L, the lower extremity of which is connected with the swinging-table, F. By the motion of the cams the lever first pushes the table back, and then allows it to fall with considerable force against two wooden stops. At the head of the table is a triangular shelf (better shown in figure G G), furnished with triangular pieces of wood, so arranged as to distribute the water uniformly over its surface. The mineral to be washed is placed in the trough T, where it is mixed with water from the shoot *h*, brought by the channel *g*. It passes from the trough to the triangular shelf, and then to the suspended table, where it tends to arrange itself according to its density, and settle as a thin deposit over the surface; but the repeated shocks which the table receives cause the particles to be again suspended, and each particle is repeatedly brought into such a position as to allow it to arrange itself, with respect to other particles, according to its size and density, and thus to become separated from the lighter earthy impurities. In Cornwall this kind of work is done by a *buddle*, or by a *rack*, which answers to the apparatus next to be described, viz. the *sleeping-tables.*

Sleeping-tables (*tables dormantes*, or *jumelles*, *i.e. twins*, from the circumstance of their being commonly arranged in pairs) are shown at G G of the steel engraving. They consist of two inclined planes, G G, varying from 20 to 25 feet in length, with rims at the long sides for preventing the water from flowing off laterally. At the upper end of each table is a triangular inclined plane, of much greater inclination than the tables, and furnished with triangular pieces of wood already noticed. At the upper point of the triangle is an opening by which the water holding the mineral in suspension pours upon the inclined plane. The mineral to be washed is placed in a small trough above the head, into which a stream of water constantly flows; here the pounded ore is kept in agitation by a small wheel *w*, set in motion by the small overshot wheel *s*, and this is worked by a stream of water from *g g′* through the shoot *h*. The mineral, thus kept in suspension by continual stirring, enters the head of the table through the aperture at the top of the triangle: but the great inclination of the triangular head prevents any deposit from being made upon it, so that the whole of the mineral is passed on to the table, the densest and richest parts remaining near the head, while the poorer parts are either deposited lower down, or are carried by the stream into the canals *m m*, in the direction of the arrows. When a certain quantity of mineral is collected on the table, the workman stops the flow at the head, and with a broom sweeps the mineral from the lower end of the incline towards the upper end: this operation is begun at the points indicated by the dotted lines: a stream of pure water is then allowed to flow over the table, which carries off any poorer particles which may have become entangled with the heavier portions. A valve is then opened near the dotted lines, and the contents of the table are swept into hutches placed below. The valve is then closed, and the operation proceeds as before. As the hutches are thus filled, their contents are generally transferred to the smelting-house. The inclination of the tables is regulated by the state of the mineral: if in fine powder, the inclination is small; if coarse, the inclination is fixed at a greater angle.

The various basins, *m m*, which receive the muddy waters, form a kind of labyrinth of great extent: they are connected with the different forms of apparatus at such points as shall ensure the reception of waters similarly charged at the same point. On quitting these basins the waters are received into large reservoirs, where the final deposit is made.

Many other processes might be described relative to the washing of ores, since these processes vary greatly in different localities, according to the nature of the ore. The subject is one that requires much skill and experience to extract from the ore its mineral contents, without loss, on the one hand, and too great an expenditure of time on the other. Of course, as the mineral increases in value, the latter item is of less importance than the former, as in the case of gold, for example. The great density of this metal, compared with the siliceous and ferruginous sand, or gravel, with which it is associated, renders its separation an easy operation. In South America the practice of hand washing is adopted, the only instrument being an iron or zinc pan, Fig. 1449, held by the knob at the bottom, and by a peculiar manipulation the lighter and stony matters are suspended and poured off, while the heavier residuum collects in the cavity at the bottom. From this residuum the gold is separated by amalgamation. In Hungary inclined tables are used; in Brazil and elsewhere a *cradle*, the construction of which will

Fig. 1449.

be evident on referring to Fig. 1450. The soil in which the gold is disseminated, is taken up in buckets, and a bucketfull at a time is placed upon the sieve: the man rocks the cradle with his left hand, dips up water with his right, and continues to pour it into the sieve until the earth is clear, in which operation a *nugget* may sometimes be met with too large to pass through the holes. When

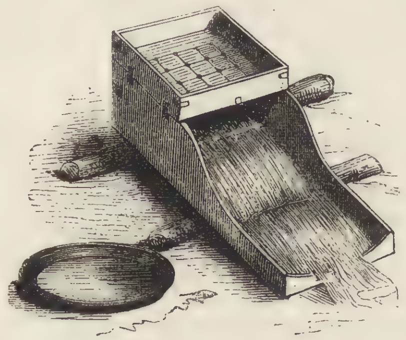


Fig. 1450.

a bucketfull has thus been washed, the man unships the sieve and throws out the stones: another bucketfull is then taken up, and when from 50 to 60 sievefulls have been washed, the rocker is cleared out, and what is deposited at the bottom is put into the washing-pan, when the gold, being the heaviest, settles.

In Siberia, the Tyrol, and elsewhere, a kind of mill, Fig.1451, is used; in the former place, for concentrating auriferous sands, and in the latter, for collecting small quantities of gold, previously extracted by amalgamation from an auriferous iron pyrites. A number of

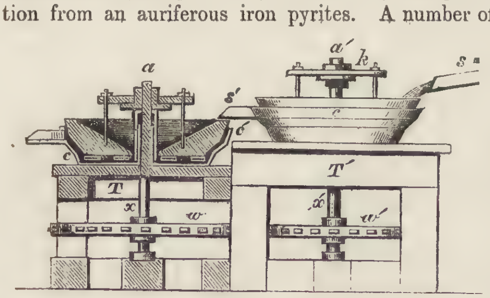


Fig. 1451.

these machines are so arranged at different levels, that the products of the first machine may pour into the second, and so on. The pyrites is reduced by the stamping mills to fine powder; a stream of water, holding this powder in suspension, is conducted into the upper mill by the spout *s*, and flowing through it, passes by the pipe *s′* into the second, and so on to other mills. The fixed part of each mill consists of a cast iron capsule *c c*, fixed by screws to the top of a strong wooden table T T′. The centre of this capsule is traversed by a rotating axis *a x*, to which motion is imparted by the spur-wheels *w w′*. The upper and movable part *m* is a muller of hard wood fixed to the spindle *a x* by an iron collar *k*. This muller has externally the same form as the internal cavity of the iron capsule, from the surface of which it works at the distance of about half an inch; but to its under surface are attached a number of ribs which nearly touch the bottom of the iron pan. The upper surface of the muller is hollowed out into the form of a funnel, into which is conducted the liquid slime, which pouring into the space between the two surfaces, flows over the sides of the basin by the spout *s* or *s′*. At the bottom of the iron pan is about half a cwt. of mercury, which forms a stratum about $\frac{1}{2}$ inch thick, and with this the pounded mineral is constantly agitated by the projecting ribs at the bottom of the muller. The particles of gold are dissolved as soon as they come in contact with the mercury, and those which escape contact in one machine, are arrested by the mercury of a machine lower in the series. The machines are kept at work for 5 or 6 weeks, when the mercury is drawn off and filtered through chamois skin, which retains a solid amalgam of gold: about $\frac{1}{3}$d of its weight is pure gold, which is separated by distilling off the mercury. It is calculated, in Siberia, that if the sand contain only 0·000001 of gold it cannot be worked to advantage. Some sands containing only $\frac{1}{8}$th this quantity, on the Rhine, for example, are occasionally washed by peasants and others, when more profitable kind of labour is not to be procured.

METER. See Gas Lighting.

MEZZOTINT. See Engraving.

MICA. A name given to a group of minerals which are finely foliated, of a pearly lustre, transparent or translucent, tough and elastic. According to Hauy it may be divided into laminæ of the thickness of only $\frac{1}{250000}$th inch. The colours present various shades of white, grey, green, brown, red, violet, and black—silver white, greyish green, and black, being the usual tints. It varies in hardness from 2 to 2·5, and in density from 2·8 to 3. The micas present several instances of isomorphism in the substitution of some of the alkaline earths for others, and an instance of di-morphism in the two varieties named *uni-axal* and *bi-axal* mica. *Potash* or *bi-axal* mica, which is the usual kind of mica, consists of silica 46·3, alumina 36·8, potash 9·2, peroxide of iron 4·5, fluoric acid 0·7, and water 1·8. It differs from talc, in affording thinner folia and being elastic, and not having the greasy feel of that mineral. It is one of the constituents of granite, gneiss, and mica slate; the lamellar structure of the latter being due to it. It also occurs in granular limestone. Mica is sometimes found in plates 2 or 3 feet in diameter, and perfectly transparent, in which state it is well adapted for use as a substitute for window-glass. Its common use in this way in Siberia, has procured for it the name of *Muscovy glass.* It was also formerly used in the Russian navy, on account of its not being liable to be broken by concussions. It is still used in lanterns and in the doors of stoves, and it is useful for holding minute objects for the microscope.

Lithia-mica or *lepidolite.* In this variety lithia replaces a portion of the alumina: it occurs in crystals of a purplish colour, and in masses of aggregated scales.

In *Magnesia-mica,* or uni-axal mica, also called *biolite,* a certain proportion of magnesia replaces alumina,

which is present to the extent of about 15 per cent. *Fuchsite* is a green mica, containing chrome. In *Plumose mica* the scales are arranged in a feathery form. *Rubellane* is a name given to red mica. *Margarolite*, or *pearly* mica, is only a variety of common mica. *Hydrous mica* contains 14 per cent. of water.

MICA SCHIST. One of the earliest groups of stratified rocks, extensively distributed throughout the mountain regions of the globe, often in contact with granite or superposed on gneiss. It is also frequently interstratified with gneiss, primary limestone, quartz rock, chloritic schist, and clay slate. Mica schist, in its most typical form, differs from gneiss by the absence of felspar. "The mica is usually spread through the rocks of this series in continuous surfaces, overspreading the quartz portions; whereas in gneiss this seldom happens. In respect of the magnitude, relative abundance, and crystalline aspect of the ingredients of mica schist, there is every possible variation, so that some specimens approach, obscurely, to granite, others to well-defined gneiss, and others to clay slate."

MICROCOSMIC SALT. Phosphate of soda and ammonia, prepared by mixing equivalent proportions of phosphate of soda and phosphate of ammonia, each in solution, and evaporating and crystallizing. A slight excess of ammonia is an advantage. This salt was originally extracted from human urine, and derived its name from the alchemists, who regarded man as a miniature of the world, or the *microcosm*.

MICROMETER. An instrument by means of which small spaces, or angles, or the apparent magnitudes of objects, viewed through telescopes or microscopes, are measured with great exactness. It was explained in the article LIGHT, that the inverted image of a bright object formed by a convex lens may be viewed by the eye-piece of a telescope, as if it were a material body; and if at the point where this image is formed, a very fine wire or a spider's thread be drawn across the tube of the instrument, it will be distinctly seen with the image. In practice, however, the wire is stretched across a sliding piece, which is moved by a screw perpendicular to the length of the instrument, and can thus be made to measure the image in terms of the revolutions and parts of the screw. An instrument of this kind is called a *wire micrometer*.

The *micrometer screw*, just referred to, is an important part of every micrometer. The following is an illustration of its use:—Suppose in the micrometer attached to a microscope, the screw has 50 threads to an inch, and carries an index which points to the divisions on a circular plate fixed at right angles to the axis of the screw. The revolutions of the screw are counted on a scale, which is an inch divided into 50 parts: the index to these divisions is a fleur-de-lis, marked on the slider which carries the needle-point across the field of the microscope. Every revolution of the micrometer screw measures $\frac{1}{50}$th of an inch, which is again subdivided by means of the divisions on the circular plate divided into 20 equal parts, over which the index passes at every revolution of the screw. In this way we readily obtain the measure of $\frac{1}{1000}$th of an inch; since 50, the number of threads on the screw, $\times$ by 20, the divisions on the circular plate, $= 1000$; so that each division on the circular plate shows that the needle has either advanced or receded $\frac{1}{1000}$th of an inch.

There are other forms of this instrument, such as the *divided object-glass micrometer* and *heliometer*. If an object-glass be divided into two semicircles or semilenses, and the two parts be moved one beyond the other, each portion will form its proper image, and the images will retreat from each other as the semilenses are moved. The semilenses are mounted on slides, and the quantity of separation is read off upon a scale. Another form of micrometer, known as the *reticule*, or *diaphragm*, is a fixed arrangement of wires or bars, applied to a telescope for the purpose of measurement. The *circular* micrometer consists of a metal ring set in the centre of a perforated glass plate, the outer and inner edge of the ring being turned true. "The plate is fixed in the focus of a telescope, and the appearance is that of a ring suspended in the heavens. The telescope is pointed, and the observer notes the time when a star disappears at the outer ring, re-appears on the inner ring, disappears again, and finally re-appears. If two stars be thus observed, it is clear that when a mean is taken of the disappearances and re-appearances of each, the difference between the two means will be the difference of right ascension between the two stars, and therefore that if one be known, the other is determined. Again, if the diameter of the ring has been determined, and the declination of the stars nearly known, the time of describing the chord of the ring will give, by an easy computation, the distance of the chord from the centre, and that the more accurately, the smaller the chord described. The sum, or difference, of these two distances is the difference of the stars in declination."[1]

MICROSCOPE (from *μικρὸς*, *small*, and *σκοπέω*, *to see*), an instrument for enabling the eye to see distinctly objects which are placed at a very short distance from it, or to see the magnified images of small objects not visible to the unassisted eye. The principle of the instrument is explained under LIGHT. For practical details we must refer to special treatises on the subject.

MILE (from *miliare*, the *mille passus*, or thousand paces, of the Romans). The length of the mile differs in different countries. The English statute mile is 8 furlongs of 220 yards each, or of 40 poles of 5½ yards, or 16½ feet each. It is also 80 surveying chains of 22 yards each. The mile in this country is therefore 1,760 yards, or 5,280 feet; the square mile is 6,400 square chains, or 640 acres. [See WEIGHTS and MEASURES.]

MILK. A fluid secreted by female mammalia, for the nourishment of their young, and it is admirably adapted by its composition for furnishing materials for the rapid growth and development of the animal. The ingredients appear to be the same in carnivorous as in herbivorous animals, but the proportions differ. Milk contains, 1. an azotized matter, *caseine*, which is

(1) "Penny Cyclopædia," article Micrometer.

nearly identical in composition with muscular flesh, 2. *fatty* principles, 3. a peculiar *sugar*, and 4. various *salts*, such as phosphate of lime, held in solution in a slightly alkaline liquid, and which contributes to the formation of bone. Under the microscope, milk appears to consist of a perfectly transparent fluid, with a number of transparent globules (of fat) floating about in it, the fatty matter forming a mechanical mixture, or natural emulsion with the watery solution. If left to itself, at the ordinary temperature of the air, a large portion of the fat globules collect on the surface, and form what is called *cream*: if this be removed and strongly agitated for a time (as in the operation of *churning*, described under BUTTER), the fat globules expel the remaining watery liquid (*butter-milk*) from between them, and unite into a mass, called *butter*. The butter is washed, to get rid of the remaining caseine, which soon putrifies, and a little salt is commonly added. If butter be intended for keeping, the butter-milk is got rid of by *clarification*, as it is called, or melting over a slow fire: the watery part subsides, and carries with it the remaining traces of the azotized matter. The flavour of the butter is somewhat injured by this process. Butter varies in consistence with the season, and probably also with the kind of food consumed by the animal. In addition to the fat, there is an oily portion, which is more abundant in summer than in winter. This oily part appears to be a mixture of oleine and a peculiar odoriferous fatty principle, *butyrine*, which has not yet been isolated, but which by saponification yields 4 distinct volatile acids; viz. *butyric, caproic, caprylic*, and *capric*. They exist ready formed in rancid butter and in cheese, and may be obtained by saponifying butter with potash or soda, adding an excess of sulphuric acid, and distilling. The resulting acid watery liquid is saturated with an alkali, evaporated to small bulk and distilled with excess of sulphuric or phosphoric acid. The mixed acids are separated by taking advantage of the unequal solubility of their barytic salts: the less soluble salts of the mixture, amounting to about $\frac{1}{20}$th of the whole mass, contain capric and caprylic acids; the larger and more soluble portion, the caproic and butyric acids. In the formulæ of these acids the carbon and hydrogen successively increase by the addition of 4 equivalents:—

Butyric Acid	$C_8\ H_7\ O_3$, HO.
Caproic ,,	$C_{12}H_{11}O_3$, HO.
Caprylic ,,	$C_{16}H_{15}O_3$, HO.
Capric ,,	$C_{20}H_{19}O_3$, HO.

The processes for converting the caseine of milk into an important article of food, are described under CHEESE. The milk may be heated to about 120°, and then coagulated by rennet: the curd is next separated from the whey by a sieve; salt is added, and sometimes colouring matter, and the whole submitted to a strong and increasing pressure, during which a peculiar kind of fermentation takes place, and principles are formed which impart a peculiar taste and odour. The best kinds of cheese, containing a good deal of fat, are made with new milk, and the inferior kinds with skimmed milk.

Milk, by being fermented and frequently agitated, yields a kind of spirit, in consequence of the caseine converting a portion of the milk-sugar into lactic acid, and another portion into grape-sugar, which becomes transformed into alcohol. Some of the Tartar tribes prepare such a spirit from mare's milk.

Fresh milk is feebly alkaline, but it soon becomes acid from the formation of lactic acid.[1] The alkaline property is due to the presence of soda, which holds the caseine in solution, and in this soluble form, caseine has the property of taking up and retaining in solution a considerable quantity of phosphate of lime. Milk varies greatly in density; that of the cow is generally about 1·030: but it varies in different animals from 1·0203 to 1·0409. According to Berzelius the specific gravity of skimmed milk is 1·033 and of cream 1·024. The following analysis of fresh cow-milk is by Mr. Haidlen.[2]

Water	873·00
Butter	30·00
Caseine	48·20
Milk-sugar	43·90
Phosphate of lime	2·31
,, magnesia	0·42
,, iron	0·07
Chloride of potassium	1·44
,, sodium	0·24
Soda in combination with caseine	0·42
	1000·00

Human milk coagulates with difficulty: it usually contains a larger proportion of sugar than cow-milk, but differs but little in the other ingredients.

The influence of food on the composition of milk is important. According to Dumas, no sugar is to be found in the milk of carnivorous animals, or in that of animals fed exclusively on animal food.

The method of solidifying and preserving milk is stated in the article FOOD, PRESERVATION OF.

MILLSTONE. In the article BREAD, the construction and use of millstones in grinding corn are explained; and it is also stated that the finest quarry of millstones is near La Ferté-sous-Jouarre, in the basin of Paris. We propose in the present article to notice this quarry at greater length, and also to refer to one or two other quarries where this comparatively rare substance is found.

The millstone of La Ferté is found in a bed of ferruginous and argillaceous sandstone, which in some parts is 20 metres thick. After passing through a stratum of sand from 12 to 15 metres thick, the presence of the millstone is indicated by a thin bed of ferruginous clay, filled up with small fragments of millstone, called by the workmen *pipois*. Then follows a layer 4 to 5 decimetres thick, composed of larger fragments of millstone, and then the bed itself, which varies in thickness from 3 to 5 metres. This bed has a very uneven surface, and seldom yields more than 3 thicknesses of millstones. Although spread over a considerable plain it is not always of sufficiently good quality to be worked. The good stone is discovered

(1) According to D'Arcet and Petit, cow's milk is sometimes acid, and sometimes alkaline; alkaline when the cows are pastured, and acid when stalled.

(2) Annalen der Chemie und Pharmacie, xlv. 263, quoted in Fownes's Manual of Elementary Chemistry, 1850.

by sounding. In some places it opens into vertical cracks, which allow the stones to be got out vertically, and these prove to be of the most durable kind. The works are quarries, not mines, for the loose nature of the superposed rock does not allow of the more economical method of driving galleries underground. The water, which is rather abundant in the works, is raised by means of buckets, attached to balanced levers which are worked by children, who raise the buckets from stage to stage. When the quarryman has arrived at the bed of millstone, he strikes it with his hammer; if the stone yield a good sound it is known to be of excellent quality and large size: if the sound be dead or dull, it will separate in getting out. The man then gets out a mass of rock and dresses it roughly into a cylinder, which according to its height will furnish 1 or 2 millstones; he sometimes gets 3, but never more than that number. He then cuts a channel, from 9 to 12 centimetres deep, round this cylinder for the purpose of separating it into 2 millstones, which he does by driving into the channel two rows of wooden wedges, and then between these iron wedges, which are gradually and equally driven all round until the mass splits asunder. The man occasionally applies his ear to the mass, to ascertain that the line of fracture is following the right direction. When millstones of large size are required, the fragments of stone are dressed into the proper shape, cemented together, and united by iron bands. Stones of this kind are largely imported into England and America.

This millstone is a siliceous rock, full of interstices or small cavities (*frasier*), which retain the grain, and the runner instantly reduces it to powder. The hard portions (*défense*) do not themselves become abraded so as to mix with the flour, as is the case with granites and sandstones. Hence the great value of this stone.

The quarries of Tartarel situated near those of La Ferté, are stated in the Jury Report, Class I., to be the most important, the number of workmen constantly employed there exceeding 200. The arrangement of the *frasier* and the *défense* in the stone of these quarries, is regarded as being best adapted to fine millwork. A complete collection of stones from this quarry was forwarded to the Great Exhibition.

The condition of the trade in 1849 is thus stated:—

2,600 stones at an average price of 250 francs per pair	325,000
200,000 segments at 3 fr. 50 c. each	700,000
Total value in francs in 1849	1025,000

At Nieder Mendig, not far from Andernach, on the Rhine, is a deposit of millstone which has been worked for upwards of 2,000 years. The rock is described as being a very hard porous lava, about 5 miles in length and 3 in breadth, and is supposed to be the product of an extinct volcano in the neighbourhood. The principal quarries are 7 in number, and the average depth is 50 feet: they are situated on an extensive plain named Hacher, about half a mile from Nieder Mendig. There are 4 classes of workmen: the *quarriers*, who get out the stones; the *lifters*, who raise them to the surface by machinery; the *cutters*, who bring the stones to the required shape, and the *labourers*, who pile the stones in heaps or assist in loading the vehicles which are to bear them away. The quarry has the appearance of an inverted cone, or of a funnel without its stem. The diameter at the top is about 25 feet, at the bottom 12 feet, and the depth 50 feet. A narrow but easy path winds spirally round this cone or shaft, by which the men ascend and descend. At the bottom the work proceeds horizontally, and the roofs of the numerous galleries formed by the excavation are supported by prismatic pillars of millstone. As very little machinery or capital is required to sink a shaft, 4 or 5 poor families unite their means to sink one; but the task of excavating 50 feet of solid rock is laborious. After passing through various layers of gravel and lava, they at length arrive at a layer of hard, blackish, heavy stone, regularly porous, and yielding sparks when struck with iron. This is the millstone. Good and well prepared tools are required to work it, after the masses have been separated by wedges and levers. The stones are brought into shape by hammers and chisels. A deep socket is cut through the middle of such stones as are intended for *runners* or upper stones, and the lands and furrows on the surface are produced by a double-edged hammer weighing 14 lbs. The stones are sent down the Rhine upon the immense timber rafts which are annually sent to Holland. At Andernach the numerous small rafts of timber with their millstone cargoes are united into one large raft.

MILLSTONE-GRIT. See Grit.

MILLWORK. See Bread—Wheels—Windmill—Couplings, &c.

MINE—MINING. The ores of the most useful metals are seldom found on the surface of the earth; they are mostly buried beneath the soil, and penetrate the solid rock often to a considerable depth: hence, if not discovered by accident, or indications of their presence do not exist on the surface, they must be sought for by intelligent inquiry, and when discovered, such methods of extracting them and raising them to the surface must be adopted as will be likely to produce a profit to the owners. This constitutes both the art and the science of mining. It is an art, inasmuch as it depends for its success on the application of rules and much local experience; and it is a science, inasmuch as it admits of the application of philosophical principles. The most successful miner is he who knows how to combine practice with theory.

In a general sense the word *mine* is an opening underground from which anything is dug, and it appears to be derived from the Latin *minare*, a word of the lower ages, signifying *ducere, to lead*; hence *to draw*, or *lead* a way or passage underground. Until the opening is made, the term *mine* is not properly applied; although it is generally used to signify the coal, iron, lead, &c. before the opening is made for digging them out.

The nature of mining operations has been already treated of at some considerable length in our article Coal, and although the extraction of metallic ores

requires, in many respects, different modes of treatment, compared with the getting out of the deposits of coal, yet the general features of the workings are similar in both cases. In one respect the mining of metallic ores has an advantage over coal, in being entirely free from the inflammable gas which is the cause of such terrible explosions in collieries.

The use of metals was almost coeval with man's existence on the earth. The Sacred Record states that Tubal-Cain, the seventh in descent from Adam, was the instructor of every artificer in brass and iron: hence, at this early period, processes were adopted for reducing the ores, and so combining them as to produce the alloy brass. Profane history also contains abundant evidence that the earliest nations of antiquity, such as the Greeks and the Egyptians, were well acquainted with certain metals. They had gold and silver in abundance; the Greeks used an alloy of copper and tin for their armour and weapons, and iron was not unknown to the Greeks and Romans. In these early ages, however, those metals which were found at or near the surface were used, and it is probable that the superficial deposits of gold, silver, copper, tin, &c., were then much more abundant than they are at present, except in the case of gold, which is now found plentifully in California and Australia in positions which require little or no knowledge of mining. When the Phœnicians traded with Cornwall for tin and lead, the rude natives obtained the supply by means of *stream-works*, as they are called. The beds of mountain streams, and the gravel or loose stones brought down into the valleys, often afford indications of metalliferous veins higher up the country. By collecting this sand and gravel, and throwing it upon an inclined plane, upon which a stream of water is conducted (whence the term *stream-works*), the lighter stones and earth are washed away, and the ore remains behind. In our own country these stream-works are confined to the ores of tin, but in other parts of the world gold, platinum, and other metals

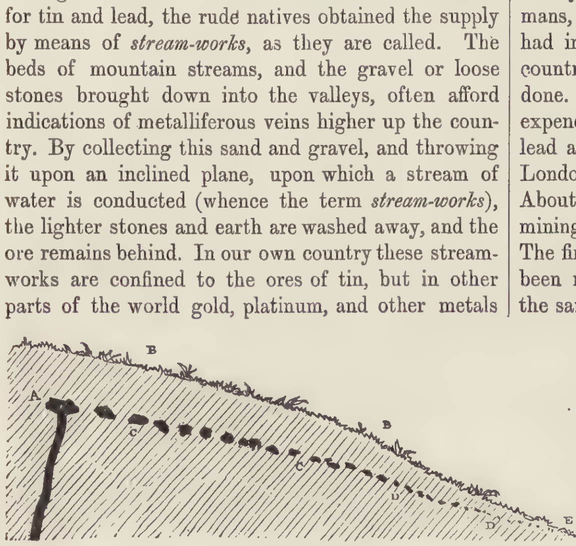


Fig. 1452.

are distributed in small grains in the sand in a virgin state, and are separated by sifting and washing. In the island of Banka, in the Eastern Archipelago, as much as 3,500 tons of tin have been annually exported, the produce of stream-works. The stanniferous gravels of Cornwall are not, however, usually upon the surface, but are covered by other gravel or by sand, clay or peat, which must be removed before the rock is reached on which the tin stones rest. The ore thus separated from the *lode* is known in Cornwall as the *broil* of the lode. In Fig. 1452, A is the *head* of the lode, C C the broil, diminishing in size as it gets further from the lode, and becoming very small as it gets nearer the surface B B E. The stream-works of Devon and Cornwall were formerly the chief source of tin ore, but they are now nearly exhausted. Streaming for tin is still carried on upon St. Austell moors, at the Pentuan Valley, and in other parts, but the chief supply is furnished by mine workings.[1]

The ancients did not, however, depend entirely on stream-works for their supply of metals. According to Herodotus, a mountain in the island of Thasos was completely burrowed by the Phœnicians in their search for the precious metals; and it appears from Diodorus that the art of forming shafts and galleries for exploring mines and extracting the ores was well known in Egypt. Early in the fourth century before the Christian era, the silver mines of Laurium in Attica were worked by the Athenians, and the quicksilver mines of Almaden in Spain were worked by the Romans.

Mining, in this its proper sense, was certainly carried on in Britain before the Roman conquest and during the Roman occupation. After the Romans had abandoned Britain, this art, in common with many others, fell into decay, the necessary consequence of civil commotion. For a long period our mines were worked by foreigners, and after the Norman Conquest, chiefly by Jews. In the reign of Elizabeth, the Germans, who had long been celebrated as skilful miners, had inducements held out to them to settle in this country, which they appear to some extent to have done. In the following reign, Sir Hugh Middleton expended the revenue which he derived from some lead and silver mines in Cardiganshire, in supplying London with fresh water by means of the New River. About this time the introduction of gunpowder into mining operations led to many decided improvements. The first use of this powerful agent is said to have been made in 1620 in Hungary or Germany, and in the same year it was introduced into England at the copper mine at Ecton in Staffordshire by some German miners brought over by Prince Rupert. It was not, however, used in Cornwall until a considerably later period.

Early in the 18th century Cornwall rose into increased importance from the recognition of the real nature of those immense deposits of copper ore, which had either escaped notice in consequence of lying much deeper than the tin, or had been confounded with *mundic*, as the common iron pyrites was called. In pursuing these rich stores to greater depths than had hitherto been attempted, and in places where hydraulic machines could not be applied, the miner

(1) We need only just allude to the use of *divining rods* and other superstitious means resorted to by miners when searching for veins or mineral deposits. Certain atmospheric phenomena popularly called *burning drakes*, by their apparent fall to the earth are even now thought to point out the situation of rich and undiscovered veins of ore. Whistling in a mine is thought to frighten away the ore or diminish its chance of continuance, and hence, however much miners may sing or halloo at their work, no boy or man is allowed to whistle.

soon felt the want of some powerful apparatus for pumping out the water which threatened to submerge his works. The first practically useful engine was constructed by Savery, who, in his "Miner's Friend," described its application to the draining of mines. This engine was greatly improved by Newcomen, and in 1705 was made the subject of a patent in the names of the two inventors. Their *steam*, or, rather, *atmospheric engine*, continued to be of great assistance, not only in the mines of Cornwall, but also in the coal mines of Staffordshire and the north of England, and it is not even yet entirely out of use, for in the autumn of 1852 the writer saw a Newcomen engine in successful operation at a coal and iron pit close to Coatbridge, near Glasgow, and the man who attended it stated that it had been at work for more than 13 years without requiring a single repair. In 1765, and the succeeding years, Watt introduced his improved engines into Cornwall, and their increased power and greater economy of fuel (the whole of which is brought from South Wales) produced the most beneficial effects on the mining interests of that county. Since the time of Watt, the Cornish engines have been in a constant state of improvement, their power having gone on improving without greatly increasing their demand for fuel: this, together with improved pumping machinery, has enabled proprietors to increase the depth of mines which would otherwise have been abandoned. The improved pumping machinery was one of the consequences of the improvements made towards the end of the last century in the manufacture of iron, the clumsy old wooden pumps having been replaced by those of iron of far greater extent and efficiency.

To the same source may also be referred the introduction of iron tram-roads, underground as well as on the surface, by which much labour was saved in conveying the mineral to different parts of the works. Great improvements were also made in the arrangement of the underground works: the present system of laying open the ground for discovery and extraction by a well-arranged series of shafts, levels, and winzes, came gradually into use, instead of the old plan of following down the ore by irregular isolated excavations, and of stoping or cutting away the ground in the bottom of the levels, as is still practised on the Continent. Not the least among modern improvements is the *man-engine*, or mechanical lift for raising and lowering the men. The labour of ascending and descending deep mines is so destructive to health, and so greatly deteriorates the working powers of the miner, as to point out the strong necessity, if only on the score of humanity, of adopting this excellent contrivance. The improvements which have taken place of late years in the mechanical preparation of ores are noticed under METALLURGY; and we cannot conclude this brief historical notice without mentioning, as an important improvement in our system of education, that a school of mines, and a mining record office, have been attached to the Museum of Economic Geology, and that similar institutions have been and are being planted in the mining districts of this country. A few years ago the Government also instituted a geological survey of the United Kingdom. The resulting geological map of England is thus referred to in the Jury Report, Class I.—"It is executed on the ordnance map prepared and published by Government. The scale of this map (1 inch to a mile, or 1 in 63,360) is sufficient to represent in detail the outline or the boundary of all the geological formations, and it even allows the direction of the principal metalliferous and other veins to be indicated when they are known for any distance. This great work, at present the only one of its kind, is a model which we may hope will be imitated by the principal governments on the Continent. Science may then, within a limited time, be enriched by a complete geological map of the whole of Europe. It is true that France already possesses a geological map, and there are also a number of departmental geological maps, many of which are executed with great talent; but these are not all on the same scale, and the details are not of the same kind; so that there are certain discrepancies which prevent our being able to unite them all in a single sheet, and thus form a complete result. The new map of France, which is in no respect inferior to the ordnance map of England, either in accuracy or execution, furnishes the groundwork for a geological map equal to that which has been prepared by Sir H. de la Beche and the officers of the geological survey. England, which laid the first foundation of the true study of stratified deposits by the sections of W. Smith, and the important map of Mr. Greenough, has still the honour of giving to the world a model for the execution of a detailed geological map, applicable at once to industrial researches and agricultural improvement."

SECTION I.—ON THE DISTRIBUTION OF METALLIC ORES.

Some acquaintance with geology is required to form an accurate notion of the various methods in which the metals and metallic ores are distributed in the earth's crust. We have seen in the case of COAL and IRON, that these important mineral substances may alternate with beds of rock of great extent, as in South Wales and Staffordshire. In other cases the mineral may occupy cracks or fissures, which have evidently been produced in various rocks by mechanical violence, subsequently to their deposition. These cracks may be formed in stratified or in non-stratified or igneous rocks; the mineral substance which fills them differs more or less from the rocks themselves, and is commonly known by the term *vein* if the contents be metallic, and *dyke* if non-metallic. [Dykes are shown at D D, Fig. 572, article COAL.] Non-metalliferous veins, usually accompanying veins of ore, and at right angles thereto, are also called *cross courses*. By far the larger number of veins are dykes, or cross courses, containing no metallic ore, or not enough to make them worth working. Should they be at all metalliferous, the minerals are seldom of the same kind as those occurring in the other lodes. Crystalline quartz and clay are chiefly found in these cross courses. The

interruptions which occur in the original veins forming what are called *faults* and *slides*, are frequently produced by cross courses. The veins which contain metallic ores are termed *lodes*, and the rock in which the lode is found is called the *country*. The dip, or inclination of the vein towards the horizon, is termed its *hade*, *slope*, or *underlie*, and its intersection with the surface forms the *strike*, and determines what is called the *run*, or *direction* of the vein. The *walls*, or portions of rock which enclose the vein are called the *roof* and the *floor*; and if the vein have a considerable inclination the upper boundary of the vein is termed the *hanging wall*, and the lower the *foot wall*. When a vein continues to be straight, it is said to be *regular;* but if it swells out in some places and contracts in others, it is then called a *pipe vein*. The expansions are termed *bunches*. Small veins passing off from the ore to the rocks are called *strings*, and when very small, *threads*. These terms are illustrated by the various dimensions of the vein *a b c d*, Fig. 1453. The miner sometimes reaches a piece of dead ground, where the vein divides into branches, a string of ore extending on either side; the vein or lode is then said to *take horse*, as at *f g*.

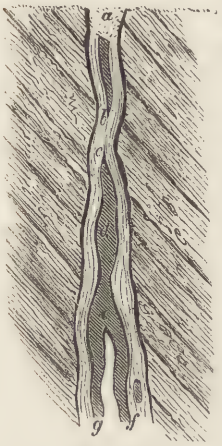


Fig. 1453.

Veins vary greatly in *extent;* they may run 5, 10, or more miles through a country, and after having been followed to a considerable depth, be abandoned on account of the difficulty of working them. Veins also vary considerably in *width*. A vein may expand to 8 or 10 feet, and contract to an inch or two across. Its value, however, does not altogether depend on its width, since a broad vein may be poor, and a narrow one rich. In Cornwall some veins 30 or 40 feet wide are less productive than those which are only one-tenth that width; while some veins, from 2 to 4 inches wide, are so rich as amply to repay the working.

It has been observed that productive veins nearly always run east and west; they are then termed *right-running* veins. The veins of lead in North Wales, Cumberland, Yorkshire, and Derbyshire, and the veins of copper in Cornwall, are mostly right-running. A similar observation applies to the veins of the mines in Brittany, the Harz, Hungary, and Mexico. The unproductive veins or cross courses, on the contrary, generally run in north and south lines across the metalliferous lodes. Veins usually occupy a nearly vertical position in the rocks; differing therefrom in the north of England seldom more than 10°; in Cornwall the deviation is said to average 20°, and in some instances to be as much as 45°.

In Cornwall the upper part of the veins are usually filled with clay, gravel, and debris, as at *a*, Fig. 1453; so that indications of metal are rarely met with at a less depth than 80 feet. The mineral contents of the vein have been divided into the *veinstone* or *gangue* and the *ore*, the former consisting of silica, or fluor-spar, or carbonate of lime, &c., all in a crystalline state. These minerals enable the miner to form some estimate as to the abundance or scarcity of the ore. The ore usually occurs in small veins within the principal vein, or in grains or crystalline masses and disseminated crystals. Where the veinstone is earthy or powdery, there is said to be generally much ore, while sterile veins are commonly filled with sandstone or clay, or with broken fragments of the adjoining rocks. A vein does not always become richer as its depth increases; but it generally happens that where the rock changes in hardness and texture, or to ore of a different character, there is an alteration in the value of the lodes. It has been remarked in Cornwall, that a vein producing copper ore in slaty ground, may enter granite without any break or change of direction, and become at first richer, and furnish ores of a different mineral character; but if traced far into the granite, it generally becomes poor. When a productive vein crosses an *elvan* or granite dyke, the ore in some cases becomes rich and abundant, and in others disappears altogether. As a general rule, the most productive veins are situated near the junction of two different kinds of rock; as in Cornwall the most productive tin and copper veins are situated chiefly in a species of clay slate, termed *killas*, and either near its junction with protruded masses of granite, or where it is intersected by channels of porphyritic rock or *elvan*. The lead veins of Wales and the north of England are chiefly situated in the carboniferous limestone and its associated rocks, especially where they are intersected and broken up by enormous faults and dislocations.

It is evident from the structure of veins that they are of more recent origin than the rocks which contain them; nor are the veins themselves of the same geological age. Werner "showed the probability that cracks and fissures which may hereafter become mineral veins have ever been, and are still forming; and he directed attention to the fragments of adjacent rocks, often found in veins, as a proof that the filling up of the veins must have been subsequent to the consolidation of the rock. But he also asserted, from observation, the important fact, that veins intersect one another, a vein of newer origin often displacing an older one, breaking its walls, and altering its texture and contents at the place of contact. A more modern fissure also often extends through the adjoining rock into an older one, and the two veins join and run parallel for a short distance, while sometimes a new fissure is permanently stopped, coming in contact with the tough walls of a former vein." Fig. 1454, which shows veins crossing one another, is copied from the Neuhoffnunger-Flachen mine, near Freyberg, in Saxony; and such an intersection of veins "can only be rationally explained by supposing that the intersection which has taken place was accompanied by a slip or fault, which has produced the shifts observed in the older vein." As a

further illustration of the complication arising from the intersection of veins in faulty ground, Professor Ansted gives a vertical section, Fig. 1455, from Huel Peevor mine, in Cornwall, in which the tin vein *a* has

Fig. 1454. MINERAL VEINS.

been first displaced by the intersection of the copper vein *b*, accompanied by an upheaval to the south S. Afterwards the displaced vein of tin, and the vein of copper, have both been affected by the fault *c*, which

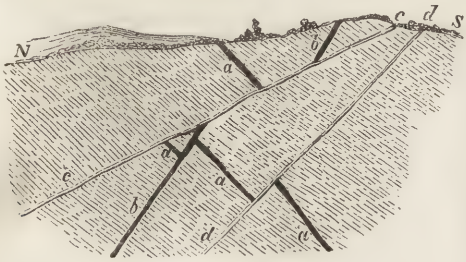


Fig. 1455.

has carried them downwards to the north N; and, lastly, the fault *d* has again heaved a portion of *a* upward to the south. Cases of this sort are very embarrassing to the miner.

These remarks respecting mineral veins may be summed up by the following general conclusions:—1. That mineral veins are of various ages, and quite independent of the age of the rock in which they occur. 2. That the fissures which now form mineral veins have not been filled up without some reference to the nature of the rocks in which they are contained, and that the filling up was therefore most probably subsequent to the formation of the fissure. 3. That the fissures which contain metallic ore are chiefly in certain definite directions, constant in the same locality in most cases, but that these are crossed nearly at right angles by another set, which are unproductive.

Section II.—Mining Operations in Non-stratified Rocks.

Such general deductions as these, the result of much geological investigation, guide the miner in his search for veins of ore. Lodes have been discovered accidentally during the formation of roads, and other operations requiring the removal of the surface soil. The operation of boring [see Boring] may also be resorted to for the discovery of ore; but there are usually indications of the presence of a lode at a considerable distance from its outcrop, such as springs of water impregnated with metal, or the shoadstones already noticed (Fig. 1452). By tracing these fragments of ore until they increase greatly in number, the upper part of the lode may be discovered. This method of tracing out the vein is called *shoding* or *shoading*. Should this method, however, fail, trenches are opened in the alluvial soil, so as to expose the solid rock, the direction of such trenches being made at right angles to the position of other veins in the neighbourhood. In Cornwall this method of finding veins is termed *costeening*. A more effectual, but more expensive method, is to excavate a nearly horizontal passage, termed a *level*, *drift*, or *adit*, from the bottom of the nearest valley into the solid rock, in the same direction as the trenches, and in this way to *cut* or intersect any mineral deposit which may exist. This plan, however, is too slow and costly to be adopted, unless the existence of the mineral veins be beyond doubt. Should the direction

Fig. 1456. SHAFT AND LEVEL.

of the lodes in the neighbourhood not be known, or it be uncertain whether the *country* be traversed with mineral deposits, shoad-pits may be formed at right angles to each other; and in this way the vein, if it exist, is almost sure to be detected. Such researches as these are not, however, of very frequent occurrence, since the chief mineral districts of this and of most other countries have been explored for ages, and the

mineral deposits well known and worked. New discoveries are chiefly made upon untried portions of old veins, or by excavating passages or *cross-cuts* in a direction transverse to that of the vein upon which they are driven, so as to prove the adjoining ground. But supposing a new vein to be discovered, and it appears to be desirable to work it, the first step is to obtain the consent of the proprietor of the land, or of the person to whom the mineral right belongs; and the next to form a company, in order to raise the necessary capital, and to distribute the risk and responsibility. Before operations are actually commenced, the bearing or direction of the vein must be ascertained, and also its dip or underlie, which may be done by sinking a few shallow pits upon it. The miners can then commence operations with precision, and they have one of two courses to adopt: they may either sink a shaft from the surface down upon the vein, or they may intersect it by a horizontal one (called a *level* or *adit*) originating in some neighbouring valley, or in some point on the slope conveniently situated for the purpose. If desirable, both methods may be carried on simultaneously. The shaft is, however, the most expeditious, and is usually adopted; and it may be sunk in an inclined direction upon the course of the vein, or if intended to be vertical, it is begun upon that side towards which the vein inclines or underlies, and at such a distance from its *back* or outcrop, as to come down upon it a given depth, such as 10, 20, or 30 fathoms, depending upon the means of the company and the prospects of success. The shaft is not sunk in the vein itself, even supposing the latter to be nearly vertical, and to afford apparently the best facilities for doing so;

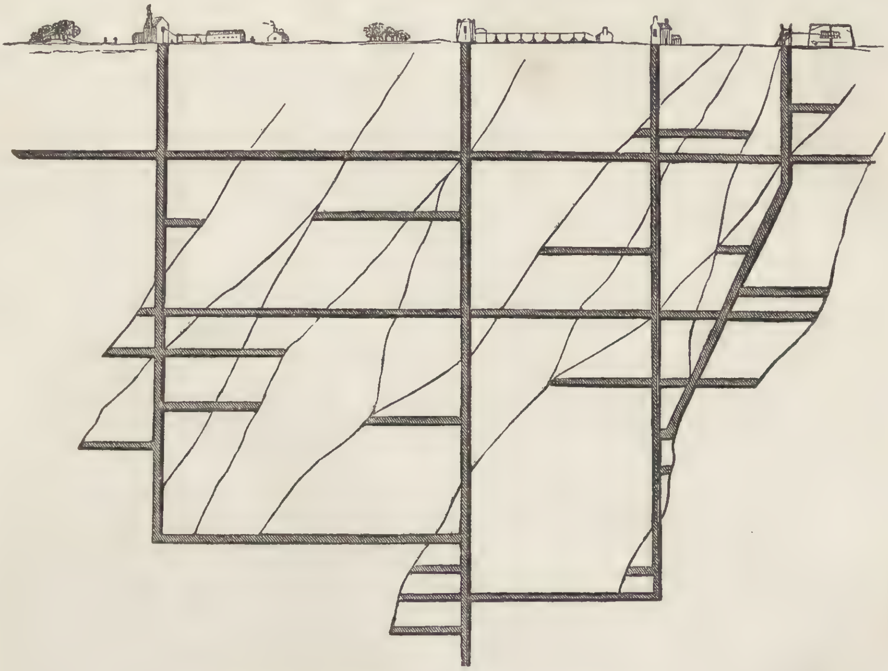


Fig. 1457. ELEMENTARY SECTION OF A CORNISH MINE.

for as the vein is in general of a more friable nature than the rock which encloses it, a shaft sunk in it would not be secure. The shaft is therefore sunk in the solid rock, and on reaching the vein, the miners alter their course from a vertical to a horizontal direction, or, in mining language, they cease to *sink* and begin to *drive.* A level is driven upon the vein in both directions; each level or gallery being made about 6 feet high, 3 or 4 broad, and rather smaller above than below. These dimensions, however, depend on the width of the vein; on its richness or poorness, as well as on the nature of the rock. If the shaft is intended to cut the vein at any considerable depth, it is desirable to approach it above the point of intersection by a *cross-cut,* and then to drive two levels at the point where the cross-cut meets the vein. In some cases, several cross-cuts are made at distances of 10 fathoms asunder, and levels are driven from each. As soon as the vein is reached the shaft may be continued perpendicularly through it, or obliquely upon the vein. The former is the more tedious and expensive plan, but, in the end, far more advantageous; the latter is the quicker and cheaper mode; it renders cross-cuts unnecessary, but it is badly adapted to the application of pumps and machinery, an evil which increases with the depth of the mine.

If, after cutting the vein, the shaft is sunk perpendicularly to the depth of 10 fathoms below the point of intersection, another cross-cut is made into it; but as the shaft is now on the other side of the vein, the cross-cuts into it will be in an opposite direction to the former ones; and as in approaching the vein they become shorter and shorter, so now, in receding from it, their length is increased. At the points of intersection, levels are driven from the cross-cut upon the

course of the vein, and in this way the shaft increases in depth, and the levels in number at the depth of every 10 fathoms, or thereabouts. Of course it is understood that ore in sufficient quantity has been found in the upper levels to warrant the continuance of the work. We are, in fact, supposing the case of a successful mine, although there are cases where the sum of 100,000*l.* has been expended before the workings began to be profitable. These details will be assisted by reference to Fig. 1457, in which the perpendicular lines are shafts, and the single lines are veins of ore. The first long horizontal line is an *adit:* the other horizontal lines are levels and cross-cuts of different lengths.

As the depth of the workings increases, the want of ventilation begins to be felt, especially in the ends of levels and those parts most distant from the shaft; so that the badness of the air arising from respiration, the burning of candles and the firing of gunpowder, compels the adoption of some method of ventilation. The simplest contrivance and the one usually adopted is to sink a small pit or *winze* upon the vein from the upper level to the extremity of the one below it. By this means an ascending and a descending current of air is produced, and the level is properly ventilated. This plan allows the levels to be continued for a very considerable distance on each side of the shaft, and winzes are formed between them at convenient intervals. By means of these winzes, also, the miner is able to examine the vein in the space between two levels, and to divide it into solid rectangular masses, which he can examine all round, and thus form an estimate of the resources of the mine. By properly laying open the vein the ore may be worked away around dead unproductive pieces of ground which are left standing to support the rock on each side of the vein, and thus supply the place of timbering. This system of winzes is found so very convenient that where the ore is tolerably continuous in driving a level, winzes are generally sunk at intervals of 20 or 30 fathoms. In sinking winzes to connect the lower levels with each other, they are usually placed midway between the winzes above, so that the ground may be explored under the middle of the rectangle formed by the two upper winzes, and the levels between which they are placed. Should the ore extend above the upper level, this part of the vein is laid open by perpendicular excavations or *rises* similar to winzes, but formed by rising up instead of sinking down. As we have already stated, the extraction of ore is not the primary object of these early workings, but should orey ground occur in the *back* or upper part of the level first driven, it is pursued upwards towards the surface, and yields the first returns to the company. When the mine has been laid out into the solid rectangular masses already noticed, other arrangements will also be in an effective state, so that gangs of men may be set to raise the ore from the most productive points. If the veins be not very hard it may be removed with the pick, but it is usually necessary to employ the force of gunpowder for the purpose. The men generally work upwards from the back or upper part of one level towards the bottom of another, and the excavations are so contrived that the ore may fall down to the level below them, whence it is conveyed in tram waggons to the shaft, and thence raised to the surface. It is usual, in well regulated mines, not to remove all the ore which can be immediately got at, but to leave it here and there to be worked as the general prospects of the mine may require, and to which the miners return if less ore be raised than could be wished. The ores thus kept in reserve are called the *eyes* of the mine, and are often of great value. When it is necessary in abandoning the mine or from other causes to remove them, it is called "picking out the eyes of the mine." Fig. 1458 shows the top of a winze, with a man winding up a *kibble*, or iron bucket in which the ore is raised. The kibble is usually made of sheet iron: it holds about 3 cwt. of ore, and it is estimated that 120 kibbles will clear a cubic fathom of rock.

Fig. 1458.

The method of ventilation by means of winzes fails to answer the purpose intended when the levels have been extended very far from the shaft: the conveyance of ore, rubbish &c., from these distant points to the shaft becomes more inconvenient and costly; so that if the prospects of the mine are favourable, a new shaft must be sunk on one or both sides of the old one, according to the direction in which the ore extends, and so placed that the new shaft may command that portion of the ore which is inaccessible from the old one. In forming the new shaft, cross-cuts are avoided as much as possible, and hence the new shaft will be made to intersect the vein at a point much deeper than the former, and arranged so as to correspond with one of the deeper levels, or with one still deeper which remains to be formed. The new shaft is sometimes sunk while the levels which are to open into it are yet distant: but the work is expedited by driving levels from the new shaft to meet those of the original shaft, and when once the two shafts are thus united, the advantages become at once evident in improved ventilation and increased facilities for getting out the ore, &c. As it is of great importance in a flourishing mine to get this second shaft into operation with all possible speed, an ingenious plan is adopted where the workings have advanced near the point where a shaft is required The site of the shaft being determined and marked out at the surface, the length, windings, and directions of the levels are accurately measured, and data are thus formed for deciding the exact spot in each level which will coincide with an imaginary vertical

line. It is next ascertained in what direction and to what distance cross-cuts must be driven from each of these points in the supposed vertical line, in order to decide upon the position of another vertical line immediately below the site of the new shaft. These nice calculations and measurements being completed to the satisfaction of the mining surveyor and engineer, a number of excavations are made simultaneously upwards and downwards in different levels, corresponding with the form and dimensions of the intended shaft which is at the same time being sunk from the surface; and so accurate has been the survey that all these separate portions of a vertical shaft unite with such exactness, that daylight may be seen from the bottom of a deep shaft formed in this manner. It is evident that by this plan much time is saved, for by working at many points simultaneously the work of many years may be performed in one or two. In the consolidated mines of Cornwall, such a shaft, 204 fathoms in depth, by being worked from 15 different points at once was completed within 12 months.

As a mine continues to be worked, the various excavations assume a complicated character in consequence of the irregular distribution of the productive parts of the vein, causing some parts to be worked more than others. Cross-cuts, too, are frequently made at various depths with a view to discover side veins, or to make trial of branches which diverge from the main lode. As the depth greatly increases, the first shafts may become useless, either from being inclined, and therefore inconvenient for machinery, or from having intersected the vein too near the surface, thus requiring very long cross-cuts before deeper levels can be begun. Hence in very deep mines a double line of shafts will often be sunk along the course of the principal veins, and three shafts may even be made to cut the same part of the vein at different depths. The most recent and deeper shafts are used for drainage and extraction, while the older and more shallow ones serve as *footways* for the ascent and descent of the miners. In some of the large Cornish mines, it is not uncommon to sink two shafts near together, one of large dimensions which is used for a drainage or engine shaft, and a smaller one for drawing stuff only. The shafts are usually rectangular in form; the *whim shaft*, or that intended for the extraction of ores, is commonly 6 feet by 4; while the engine shaft may vary from 6 feet by 8, to 8 feet by 10, and even larger. Fig. 1459 represents what is called a *platt*, that is, a sort of cavity at the extremity of a level, near the whim shaft, for the purpose of collecting supplies of ore for filling the kibbles which raise it to the surface. The sketch is supposed to be taken from the side of the shaft; the men are boring in order to place a *shot* for blasting so as to enlarge the platt. The kibble shown is not of the regular size such as is used for raising the ore, but a smaller one used for temporary purposes such as this. The hole over which the kibble hangs is a small *sump* or cavity about a foot in depth, cut at the bottom of the shaft for receiving the drainage water. Fig. 1460 shows a platt complete: the sketch was taken in East Wheal Crofty, from the end of the level which opens into it. This platt is not at the bottom of the shaft as in the former case, but at the adit level. The kibble is seen hanging in the shaft, which is boarded off from the platt to prevent accidents. When an empty kibble comes opposite the door, the *filler* pulls it in towards him with a long iron hook, and, having landed it on the platt, fills it.

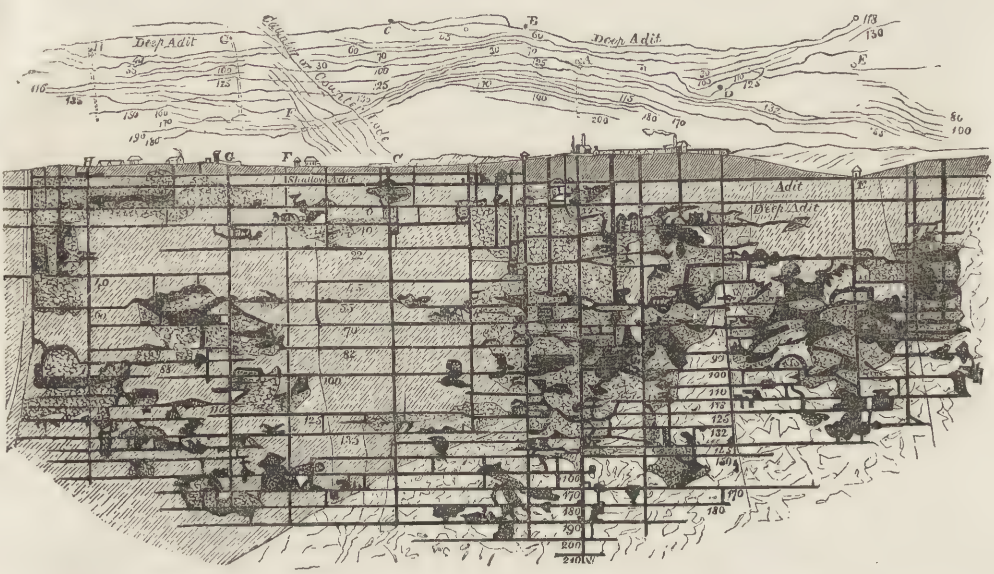

Fig. 1459.


Fig. 1460.

When a level opens to the surface at the side of a valley, it forms what is termed an *adit*, or *day-level*, and most mines have at least one for the purposes of drainage. Where the mines are situated near the deep ravines of mountainous countries, a succession of adits may be driven in, one below the other, so as to prove the mine, and drain it, more or less, completely. Where a mine has been opened by sinking down from the surface, as is most usual, an adit is commonly begun from the bottom of some neighbouring valley, and is driven towards the vein with a slight inclination, to allow the water to flow through it. Adits of enormous length have been formed in some mining districts, so as to traverse a number of mines, and carry off the water at the lowest practicable point. One of the most remarkable works of this kind is the *Great Adit*, or principal level of Cornwall, through which the waters of the numerous mines in Gwennap and Redruth are discharged. Its length, inclusive of its various branches, is about 2,600 fathoms, or nearly 30 miles. The greatest length to which any branch appears to have been extended from the adit mouth is at Cardrew Mine, and measures about 5½ miles. The highest ground which it has penetrated is at Wheal Hope, where the adit is 70 fathoms deep. This adit is 39 feet above the

level of the sea at high water, in Restronget Creek, into which the waters discharged from it flow, its mouth being near Nangiles, in a valley communicating with the creek.

The foregoing details will be assisted, as well as illustrated, by the plan and section of a portion of Dolcoath Mine, Figs. 1461, 1462. In the upper figure, or plan, the ground is supposed to be either removed, or transparent, so as to show the underground levels, adits, &c. Numbers are attached to the lines which represent the levels driven upon the lodes, and these numbers give the respective depths beneath the adit,[1] so that if perpendicular lines were let fall from this level upon such lines, they would cut them at the various depths marked, such as 60, 70, 80, 100, or any other number of fathoms. It will be observed by the increase of the numbers marked on levels to the southward, that the dip or underlie of the lode must be in that direction; and further, that lines representing equal depths are much closer to each other in some places than in others, showing that the lode approaches more towards the perpendicular in those places than in others. In reality, these lines are far more irregular than they are represented in the plan. Thus, while the engine shaft is inclined with the dip or underlie of the main lode, the



Figs. 1461, 1462. PLAN AND SECTION OF PART OF THE MAIN LODE IN DOLCOATH MINE.

Gossan shaft is sunk perpendicularly; so that cutting the plane of the lode somewhere near the 125 fathom level, cross-cuts are made to communicate with it at less depths from the north, and at greater depths from the south, in order that the ores raised at these levels may be brought to it, and lifted to the surface. Several other cross-cuts will be observed on the plan, some of which are merely for the purpose of uniting the various parts of the mine conveniently together, while others act as channels for draining the waters, so that they may be brought to the most convenient place for pumping. Cross-cuts of this kind will be seen between the North Entral lode and the main lode at the various depths of 40, 70, 80, 100, and 120 fathoms and the levels upon a southern lode, known as the *Caunter*, will be seen to cut across or abut upon those of the main lode, where the two lodes meet.

This plan, therefore, shows the mode in which the levels on the lodes, the shafts, the adits, and cross-cuts occur. We now turn to the section, in which the lines of levels and letters of reference correspond with the plan. If we suppose the south side of the main lode at Dolcoath, and consequently, as it underlies south, the upper or *hanging* wall to be removed, we should have such a section of the workings as is here represented. In this section, those portions which have been cut for galleries in the levels, the shafts, and where bunches or accumulations of ore have been found, are left blank; and those parts in which the rubbish of the workings (called *deads* or

(1) In most of the Cornish mines the depths are reckoned from that of the adit, and not from the actual surface of the country, which often undulates considerably, so that a given level may be 100 fathoms beneath such surface at one place, and only 50 fathoms at another. By thus reckoning from beneath a well-known level, such as that to which the water is pumped up, a more accurate idea may be obtained of the depth of the workings than by reckoning from the surface. The greatest depth that has been attained by mining is in the now abandoned Kuttenberg Mine, in Bohemia, which was 3,778 feet. Some of the shafts in the Newcastle coalfield are 1,800 feet deep. Most of the deep mines are in Prussia, Norway, the Tyrol, Bohemia, &c., but their depth is reckoned from the surface of the ground, which in mountainous countries may be many thousand feet above the level of the sea. Thus, at the Joachimsthal Mine, in Bohemia, the surface is 2,388 feet above the sea, and the depth 2,120 feet; so that the bottom of this mine is actually above the sea level. The Valenciana Mine, in Mexico, is 5,960 feet above the sea, and its deepest workings are 4,274 feet above that level. The greatest depth below the sea level is said to be a boring at Minden, 2,231 feet deep, of which 1,993 feet are below the level of the sea.

attle) has been thrown back, and so arranged that the galleries or levels, and the shafts, should pass freely through them, are represented as composed of broken fragments. The killas or slate remains white, while the granite is dotted. We see that this main lode cuts into granite in its eastern prolongation; and a tabular piece of granite, forming a projecting mass or vein from that rock, at a higher level, being cut by the lode at a short distance from the main mass of granite, appears as if separated entirely from it amid the slate. The bunches of ore will be observed to have occurred very irregularly, and the places which they occupied, in a great measure, will be seen filled up with the rubbish taken from the non-productive workings of the mine. Levels on the east have been driven into the granite in search of bunches of ore, and in both directions the search was abandoned.

It will be seen that the *sump* or lowest part of the engine shaft s forms the lowest part of the mine, as already noticed. At the time when this plan was made, the ores were drawn up to the surface by four shafts, by the three steam-whims; but the position and number of the shafts varies with the state of the mine, so that many shafts may exist which are not used for drawing ores or for pumping. This is now the case with several shafts on the main lode at Dolcoath, including an old pumping-shaft. As every shaft has its name, and every level is known by its depth, the position of work in any part of the mine is at once comprehended by all. A mine, in fact, resembles a town, of which the streets are known by names, and the houses by numbers.

The various cross-courses traversing the lode are also marked and named; and although these, when they heave the lode considerably, bar the progress of the miner, or cause a great increase in the influx of water into the mine, are injurious, at other times they are highly useful, by keeping out the water of a neighbouring mine. In the latter case they are, in consequence, preserved uncut, as in Dolcoath Mine, where the great cross-course on the east of the lode is untouched, except at the adit-levels which traverse it. This cross-course has cut through the lode, the continuation of which is worked in the adjoining mine of *Cook's Kitchen*, and heaved it, so that a line prolonged from one would not strike the other; and it lately kept out a body of water which had accumulated in the old workings at Cook's Kitchen. Such main cross-courses, which frequently bound setts, and thus often separate old mines, are carefully preserved, so that the failure of one mine does not cause its waters to pour in and deluge the other, beyond the power of its engines to clear it. In different parts of the same mine, the cross-courses are in part preserved, in order to keep out the water from the deeper levels, when this can be done conveniently. On the west of the section the workings do not reach a cross-course beneath the 40-fathom level, though, from a shaft having been sunk upon it, the workings which reach it on the east side are deeper. Cross-courses are found extremely useful for driving adits upon, and as they generally cut the lode at considerable angles, the work thus carried on exposes a good section of the *country*, as it is termed, or rocks on both sides, and consequently of any lodes which may there occur.

The distances at which the levels have been driven from each other are very irregular upon this lode, except in the lower workings, beneath those of 150 fathoms, which have been made more in accordance with the modern practice of forming them 10 fathoms from each other, as will be seen in the section, where we find complete regularity in this respect from the adit to the 90-fathom level. The workings beneath that level have been driven for discovery, and at greater distances, to save expense. On this *caunter* or *contra* lode, which is worked through *Harriett's* lode up to the main lode, considerable expense was incurred in driving levels, both in the depth and towards the eastward, in search of ore, which was unattended with success. These heavy expenses on account of discovery can only be profitably borne by mines of a certain magnitude, which, throwing up a fair general amount of ores, can afford to put aside a certain proportion of the profits for discovery.

Section III. Mining in Stratified Rocks.

The foregoing details refer to those countries where the rocks explored exhibit no distinct traces of stratification, and the metallic veins extend to unknown depths. The mining districts of Cornwall, Saxony, and Mexico are examples. In countries where the rocks are stratified, mining operations necessarily assume a different character; the vein, instead of extending throughout the rock, as in the former case, is chiefly confined to rocks of a certain class, the intermediate strata being unproductive. Thus the carboniferous limestone of North Wales, Derbyshire, and the north of England, is rich in lead, while the superincumbent grits and shales are unproductive rocks. All, therefore, that is necessary is to work into the limestone, for which purpose the mountainous character of the countries indicated is highly favourable. Some point is selected in a valley or ravine at the outcrop of the strata, and from thence a level,

Fig. 1463.

L, Fig. 1463, is driven in a rock which is known to be favourable to the mineral deposit, and where practicable the level is driven into the vein itself, which thus affords effectual means for exploration and facilities for getting out the ore. Should the ore not be discovered in driving the level, cross-cuts are made in one of the adjoining strata. When bunches of ore are found, excavations are made in them upwards and downwards, so as to lay them open for convenient extraction. If the ore extend up towards the surface,

another level, L', may be driven from the *rises, r,* above the first level, and similar operations be carried on in any productive stratum that may occur. When the vein has thus been laid open for working, the masses of ore are got out either by the pick or by blasting, and the stuff is made to fall into the lower level, whence it is conveyed in trams to the entrance. The principal level is driven, if possible, upon the lowest productive stratum, so as to serve for drainage and extraction. The work is thus carried on by a system of rises, unless, indeed, a discovery should be made of ore below the principal level, in which case it is got at either by means of another day level or by means of winzes, *w*. When, however, the level has been carried to a considerable distance from its mouth, a shaft may be required, not only for the purposes of ventilation, but also for working the mine.

Section IV. Mining Tools and Processes.

The tools employed by the miner in excavating the vein or rock are very simple; the *pick, a,* Fig. 1464, the *wedge* or *gad,* and the shovel, *b,* being used for excavating soft ground; and the *borer* or *jumper, d,* with a hammer, *c* for striking it, when the rock is so hard as to require the use of gunpowder. The pick, *a,* resembles a common pickaxe, but smaller; the iron head is sharp and pointed at one end, and very short and hammer-shaped at the other; this tool is much used both in working in the rock and in breaking down ore. The wedge or gad is of wrought-iron, and often with curved sides: it is used for driving into crevices of rocks or into small openings made with the pick. The shovel is pointed, to allow it to penetrate among the coarse hard fragments of mine rubbish, and its handle is somewhat bent. The borer or jumper, *d,* is an iron rod or bar about 2 feet long, steeled and formed into a flat sharp edge at the end: it is driven into the rock by one man with the hammer, *c,* while another man turns it after every blow, so as to expose fresh surfaces of the rock to the edge. The pulverised matter thus produced in the hole is drawn up from time to time with a *scraper, g,* and when sufficiently deep, the hole is charged with powder, and the needle or nail, *f,* a small taper rod of copper, is inserted so as to reach the bottom of the hole which is next to be *tamped* or filled up with some substance, such as dry sand or tough clay, which will firmly hold the powder and prevent the explosion from taking effect by way of the hole. Small quantities of this substance are introduced at a time, and rammed firmly down by means of the *tamping-bar, h,* the divided stem of which allows the needle to pass up between the prongs. The tamping-bar is held firmly by one man and struck by another with the hammer, — a dangerous operation, and still more so when the tamping-bar was of iron, instead of being, as it now is, faced or tipped with copper. Fig. 1465 represents two men at work in an *end.* One man is getting a hole ready for tamping, while another is pounding some stone for tamping upon another stone held between his knees. When the hole is filled the nail is withdrawn by putting a bar through its eye and striking it upwards. In this way a small vent-hole is left for firing the *shot,* as the charge of powder is called. A train of gunpowder is next laid and fired by a *smift* or slow match, which may be a long green rush with the pith removed and then filled with powder, or merely a piece of brown paper smeared with grease: the miners then withdraw until the explosion is over. When the rock is wet, a tin cartridge, *i,* is used. A *safety-fuse,* now in use in Cornwall, has been the means of saving life to a large amount. This fuse is made by machinery: string is coiled so as to form a cylinder, which receives the powder specially manufactured for the purpose, and by a continuous operation, enormous lengths of the fuse are formed. In practice the charge of powder is placed in the hole, and the required length of fuse carried down to it. The hole is then tamped, and the fuse carried out at the top of the hole. When everything is ready, the

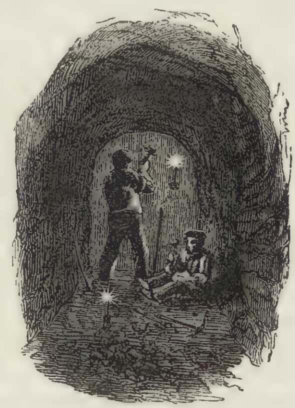


Fig. 1465.

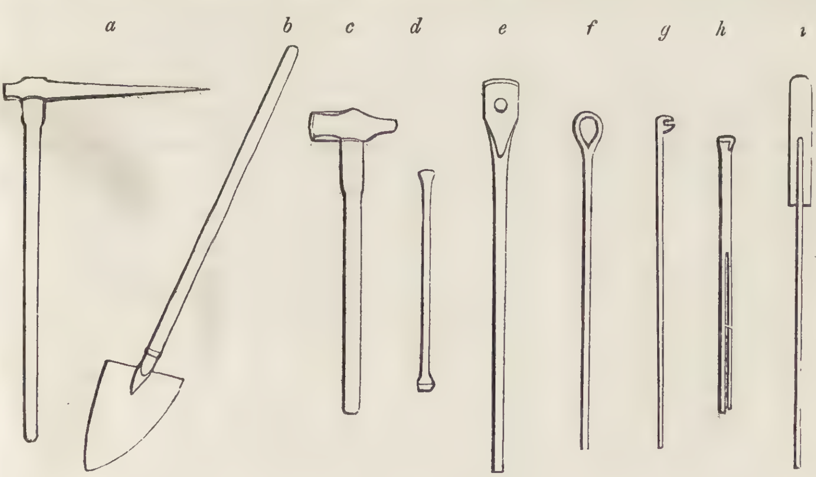


Fig. 1464.

miner lights the end of the fuse, and as this burns slowly he can withdraw safely before the explosion takes place. *Blasting cartridges* are also in use: an elastic substance is placed in the upper part of each cartridge to prevent the possibility of an explosion in tamping: the safety-fuse is united with the cartridge. When used in wet ground or under water the cartridge and fuse are coated with pitch or gutta percha.

According to Overman,[1] "If holes for blasting cannot well be drilled they can be formed by acids. Pyrites may be penetrated by nitric or muriatic acid; also native metals, such as copper, limestone, and magnetic iron ore, may be dissolved by any acid; the muriatic is, however, the most generally used. In this case we cannot sink any other form of hole than a vertical one. The manipulation is easily performed by setting a glass tube vertically upon the rock, and providing its top with a funnel and apparatus, so as to let in the acid drop by drop. If the pipe is close fitting to the rock, and the acid poured in very slowly, the hole will not be much larger than the glass pipe. The tube must descend with the bottom of the hole, and be always close to it. This operation works very slowly, but in pyrites, or compact magnetic iron ore, which cannot be penetrated by steel tools, it is a useful method of preparing a hole for blasting."

At Rammelsberg, in the Hartz, on account of the hardness of the rock, the ore is got out by the direct action of fire. The substances in the workable mass are copper and iron pyrites with galena accompanied by quartz, carbonate of lime, compact sulphate of baryta, and sometimes grey copper ore, sulphuret of zinc and arsenical pyrites. The general system is as follows:—An advance is made towards the deposits of ore at different levels by transverse galleries proceeding from the shaft and terminating at the wall of the mass. Large vaults are formed by means of fire in the heart of the ore. The vault is, however, first opened by blasting, after which it is enlarged by fire; for which purpose billets of firewood are piled up and made to rest against the ore, so that when set on fire the flame may play against the mineral mass which is to be detached. The faggots are distributed in the vaults of the different levels during the week, and are fired on Saturday, the upper vaults first, and when one fire is fairly kindled, the next below it is lighted. The effect is said to be exceedingly grand. Soon after the flame has touched the ore, a strong odour of sulphur, and sometimes of arsenic, is disengaged, and loud detonations are heard, accompanied by the fall of flakes of ore. The flame assumes various colours, arising from the volatilization of sulphur, zinc, arsenic, &c., and the ore is brought into that state in which it can be easily detached by long iron forks. The combustion goes on till Monday morning, when the firemen enter the mine and extinguish the fires. On Tuesday the people are busy in detaching the ores, sorting them and taking them out, and the remainder of the week is employed in building up fresh faggots. In proportion as the roof is scooped out in this way, the floor is raised by means of terraces formed from the rubbish.

(1) Treatise on Metallurgy, 8vo New York, 1852.

Section V. Drainage, Ventilation, Timbering, &c.

We have hitherto referred only incidentally to the important subjects of drainage, ventilation, timbering, and the best means of extracting ore and rubbish.

Unless mines are worked by means of day-levels or adits, and even then if the workings are conducted below the principal level, water filters rapidly into the mine, and the more so if the rock is porous, or if this be compact the mineral vein itself is likely to be porous. The waters which pour into the workings may be got rid of by means of adits, as already noticed; but should the nature of the country prevent their adoption, mechanical power must be resorted to, as indeed it must be wherever the workings are below the adit level. The simplest apparatus used for the purpose of drainage is the *horse-whim, whimsey*, or *gin*, which is used not only to raise the water but also the stuff got out in sinking. It consists of an upright shaft, carrying a large drum and projecting arms or levers, to which horses are attached for turning it round. Round the drum is coiled a rope, the two ends of which, after being guided over pulleys, pass into the pit: a large bucket, kibble, or corve is attached to each end, so that while the rope is winding or unwinding on the drum, one full bucket is ascending, while the other, the empty one, is descending the pit. Where mines are not very deep, or where the quantity of water to be raised is trifling, this apparatus is of use, but it cannot be applied on a large scale. Where the locality is favourable for the purpose, water power is admirably adapted to the requirements of a mine. The German miners took advantage of this steady and economical first mover at an early period, and applied it with remarkable skill, as they still continue to do. In England, the great abundance of coal has led to the steam-engine being chiefly employed in draining mines, and also in raising the ore, &c.; although, where circumstances have been favourable, water power has also been employed. In the application of water power, the nearest stream is conducted into an artificial channel or *leat*, and conveyed into the mine so as to have a sufficient fall to turn an overshot wheel; the water which passes off from the tail of this wheel is made to do duty again upon another wheel at a lower level; a third wheel, still lower, may also be set in motion by the waste waters of the second and first; and so on as long as a sufficient fall can be produced. The wheels vary from 10 or 12 feet in diameter to more than 50, and from 2 or 3 to 6 or 7 feet in breast. Some of the largest are upwards of 100 horse-power.

The pumps used in mines do not act on the principle of atmospheric pressure, as in the household pump, but they are simply *lifts* or columns, sometimes 20 or 30 fathoms in height, and 10, 12, or more inches in diameter; at the foot of each column is a cistern, into which the water of the column next

below is discharged. The whole column of pumps is worked by a single piston-rod passing down the middle and communicating with each column by a rod attached to its side. A reciprocating motion is imparted to the main pump-rod, by means of a crank on the axle of the water-wheel attached to one end of a horizontal rod, the other end of which is fixed to a *bob*, or upright post, movable on a centre and braced to a horizontal piece framed into it at the bottom, the further end of which is connected with the pump-rod. In this way the rotatory motion of the water-wheel is converted into a steady reciprocating motion when communicated to the pump-rod. It is necessary, however, to counterbalance the weight of the pump-rod, which is done by means of a large box filled with stones, iron, &c., attached to the opposite end of the balance-bob. The pumps are of iron, and allow the columns to extend to a great depth without leaking or danger of bursting. In some of the German mines, where the supply of water is limited and a considerable fall can be obtained, the *water pressure engine* is used.

Some of our deepest and most extensive mines owe their great depth and extent to the progressive improvements which have been made in the steam-engine. In Cornwall, where the cost of carriage renders fuel comparatively high priced, improvements have been made in the engines, chiefly with reference to economy in fuel,[1] and the efficiency of a steam-engine for mining purposes is estimated by the amount of work performed with reference to the consumption of a given quantity of coal. This is termed the *duty* of the engine, and it is expressed by the number of millions of pounds raised 1 foot high by a bushel or 94 lbs. of Welsh coal. In a pumping-engine, the data for this calculation are the quantity of water discharged from the pumps in a given time, and the quantity of coal consumed by the engine in the same period. The progressive improvement of the duty of steam-engines will be seen from the following statement:—

	lbs.	
In 1769, the old atmospheric engine, by consuming a bushel of coals, raised	5,500,000	1 ft. high.
,, 1772, as improved by Smeaton	9,500,000	,,
From 1778 to 1815, the steam-engine as improved by Watt	20,000,000	,,
In 1820, as improved by the Cornish Engineers	28,000,000	,,
,, 1826, ,, ,,	30,000,000	,,
,, 1827, ,, ,,	32,000,000	,,
,, 1828, ,, ,,	37,000,000	,,
,, 1829, ,, ,,	41,000,000	,
,, 1830, ,, ,,	43,350,000	,,
,, 1839, ,, ,,	54,000,000	,,
,, 1850, ,, ,,	60,000,000	,,

These numbers indicate only the average duty: many engines greatly exceed the last-named result; as for example, at the Consolidated Mines in 1827, the highest duty was 67,000,000; at Fowey Consols in 1834, it was 97,000,000; and at the United Mines in 1842, it was 108,000,000. Still greater improvements may be expected; for it appears from the experiments noticed in our article FUEL, vol. i. p. 725, that the duty falls very far short of the actual force generated.

The steam-engine employed in pumping, is erected close to what is called the *engine-shaft;* one end of the beam, to which the pump-rod is attached, is situated over the centre of the shaft; the pump-rod is counterbalanced by a balance-bob, as in Fig. 1471, so that the power of the engine is not wasted in lifting the pump-rod, which is very ponderous, but is employed in raising the column of water in the pumps. The diameter of the cylinders used in the construction of these engines, varies from 40 to 90 inches; the latter being equivalent to 300 horse-power. High-pressure steam of 40 or 50 lbs. to the square inch is used expansively; the communication with the boiler being cut off at $\frac{1}{4}$th or $\frac{1}{5}$th of the stroke; a short interval is also allowed between each stroke for the perfect condensation of the steam, and the boiler and cylinder are carefully cased in so as to prevent

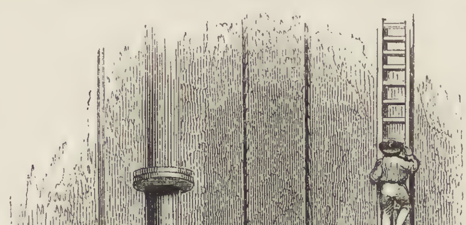


Fig. 1466. INTERIOR OF A SHAFT.

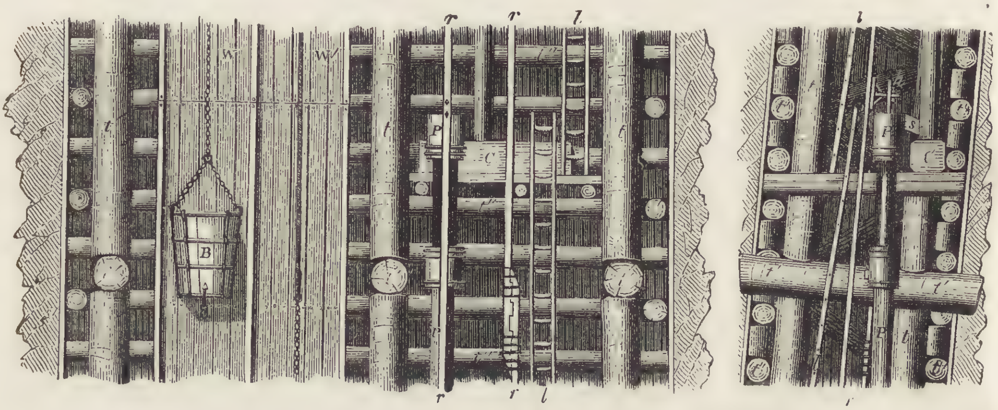
loss of heat by radiation. Fig. 1466, shows the interior of a Cornish shaft, with the engine-pumps, ladders, and kibbles; the last ascending and descending. In general, the portion of the shaft where the kibbles pass is boarded off from the rest to prevent accidents

(1) Some idea of the extent to which steam-power is employed in Cornwall, may be formed from the following brief statement of the quantity of coals consumed per month at a few of the principal mines:—

	Bushels of 94 lbs.
Fowey Consols, 1835	101,246
Godolphin, 1839	129,801
Fowey Consols, 1840	203,699
United Mines, 1842	84,862

by any portion of their contents falling out, or from their swinging by striking against the sides. The entrance to a level is shown on the left.

Some idea of the elaborate and apparently complex arrangements of a shaft is better conveyed by Figs. 1467, 1468, which represent the same shaft under different points of view, one at right angles to the other. The methods of supporting the walls are shown by the timbers *t t'*: the miners ascend and descend by the ladders *l l'*: P P are the pumps, the pistons of which are worked by the rod *r r*, the connexion with the piston rod being made as shown at *h*: each pump discharges into a cistern C, by a shoot *s*, and into this cistern the lower extremity of the barrel of the pump next above dips. W W' are corve ways by which the ore, &c. is raised in buckets B. This shaft is sunk in the line of the vein, the rock enclosing it being indicated at the sides of each figure.



Figs. 1467, 1468. VERTICAL SECTIONS OF THE SHAFT OF A MINE IN GERMANY.

It is evidently necessary to the permanency of a mine, that in excavating the enormous quantities of ore and rubbish which are being constantly brought up, the roof be prevented from falling in and involving everything in ruin. Support may be given to the roof by means of pillars left in the vein, the poorer portions being selected for the purpose; or by walling either with brick or stone. But the most common and convenient mode of support is by timbering. If, from the friable nature of the rock, a shaft require support, four pieces of strong timber are framed into each other, and a number of such frames being fixed at intervals of about 4 feet apart, the intermediate spaces are filled up with boards driven between the frames and the rock. Levels are supported by three pieces of timber arranged in the form of a doorway, rather narrower above than below, and framed together at the top; the ground between every two doorways being supported by planking. The large open excavations or *gunnies*, from which ore has been removed, are kept open by means of strong pieces of timber placed, as shown in Fig. 1469,[1] so as to press against the two walls of the vein, which are thus prevented from closing in. These gunnies are useful receptacles for the deads and *attle*, or rubbish which are constantly accumulating from the workings carried on in the rock or unproductive parts of the vein. A gunny is prepared for the reception of the rubbish, by placing in the backs of the levels strong timbers, upon which boards are laid so as to form a close covering or *stull*, and the deads and attle being thrown upon it until the space above has been filled up. Walls of the vein are in this way supported, while much useless material is got rid of. There still, however, remains a large quantity of rubbish, which cannot thus be provided for, and it is sent up the shaft to swell the waste heaps which form a conspicuous feature at the surface of every mine. The extraction of an extensive mine is so great, that the quantity of ore raised is seldom more than ⅙th or ⅛th, and even less, of the mass of stuff which is raised to the surface. At the Consolidated Mines in Cornwall, some years ago, the daily extraction was about 200 tons, a large proportion of which was raised from a depth varying from 200 to nearly 300 fathoms. The timber used in the mines of Cornwall and Devon is Norwegian pine, which is admitted free of duty for mining purposes; and so great is the quantity in actual use, that, according to a calculation some years ago, 140 square miles of Norwegian forest would be required to afford a supply for these mines.

Fig. 1469.

As there are no noxious or inflammable gases generated in these mines, the ventilation is much more simple than that required for a coal-mine. [See COAL.]

(1) This figure represents a man at work in a *pitch* in the back of the level. The two men below are driving an end.

It is carried on simply by communication from shaft to shaft by the different levels, and from level to level by means of the winzes. When these communications are properly made, currents set in in different directions, varying according to the temperature at the surface and the increasing temperature at different depths.

The temperature of mines opens an interesting question on the subject of terrestrial heat. At no great distance below the surface, but varying in different places in some degree according to the nature of the rock, the effects of atmospheric temperature begin to cease. According to the experiments made in the caves of the Observatory at Paris, the annual or diurnal variation of temperature ceases at the depth of 25 feet. In various Prussian mining establishments the same result has been obtained at depths ranging from 27 to 63 feet. In the neighbourhood of Edinburgh, according to Forbes, the effects of atmospheric temperature are no longer appreciable at 55 feet depth in trap rock; at 65 feet in loose sand, and at 96 feet in compact sandstone. Below the point where external causes of heat cease to operate, it has been found, from abundant observations in different parts of the world, that a progressive elevation of temperature takes place from some internal cause proportionably as the depth is increased. The rate of increase differs in different localities in consequence of difference in the nature of the soil and the rock, and from the varying elevation of the sites. According to a series of observations by Mr. Henwood the following results were obtained by taking the temperature of the water as it oozed from the rock, before it was influenced by the temperature of the levels:—

	Depth.	Temperature.
At St. Just	150 feet	51°
"	420 "	56
"	768 "	62
At Redruth	198 "	52
"	456 "	58
"	780 "	70
"	1,062 "	86
"	1,470 "	89

Similar results have been obtained in the mines of Saxony and elsewhere. The rapid increase of temperature at great depths considerably increases the difficulties of mining.

Section VI. Economy of Mines.

With respect to the internal economy of mines, Mr. John Taylor, after remarking on the mechanical improvements which have taken place in the art of mining, says:—"Important as the improvements are which we have contemplated in the instruments which the progress of physical science has placed in our hands, those which relate to the government of large bodies of workmen, to the inducement to active enterprise on the part of the labouring miners, to the removal of difficulties in their way, or of placing them in circumstances most favourable to effective exertion, are even more important, and to this may be added the judicious application of those very inventions which have been noticed. It must be recollected, that, after all, the great expenditure in mining is for manual labour, and that we have no means as yet devised for penetrating the rocks which contain mineral treasures but those afforded by the patient and unremitting labour of a great number of men. The regulation, therefore, of this force, and its due application, is after all more important to the success of mines than even the most ingenious mechanical expedients."

Fig. 1470. THE CORNISH MINER.

The underground work of Cornwall, and most other districts, is of two distinct kinds; *dead-work*, also called *tut-work*, or that which is carried on in the rock, vein, or deposit, for the purpose of discovery; and *productive labour*, called *tribute*, which consists in the breaking down and extraction of the ore. Each kind of work is performed under a series of contracts which unite for the time the interests of the miner and his employer, and lead to a skilful division of labour. The practical direction of the works is confided to agents named *captains*, who are generally selected from the most intelligent workmen. In the larger mines their duties are divided. A captain of the greatest experience usually governs the rest, and in conjunction with, and under the advice of, one of the partners or the principal manager, attends to all the business of the concern; while the departments of account, of the construction and care of engines, of the purchase of the various articles used, of the ore-dressing, &c., are superintended by persons appointed by the manager and principal captain. The captains under the chief have different duties assigned them: those employed underground see that the work is there conducted properly; while the *grass-captains* superintend the work on the surface, such as the dressing of ore, &c., which is done in the *bal*, or upper part of the mine. Engineers are also appointed, and to them is confided the care of the various engines and machinery.

The persons working under the captains are divided into *tributers*, *tut-workmen*, and *labourers*. Tributers are men who agree to work a portion of a lode for a given time in the best manner they can, receiving as remuneration a certain portion of the value of the ores raised, as may be agreed upon. This portion necessarily varies according to the value of the part

of the lode which is likely to be worked in the given time, usually one or two months. Thus, if the lode be rich, and is likely to continue so, a smaller portion of the value of the total quantity of the ores raised by the miners, taking the *pitch* or lode to be worked in the given time, is agreed upon, than when the lode is somewhat poor and may continue so. The mode in which the agreement is made is as follows:— Upon the *setting-days*, as these agreement-days are termed, the miners assemble before the counting-houses, and meet the captains, who have previously examined the various parts of the mine, and determined what they consider fair terms upon which the various pitches should be *set* or granted. The men, on the other hand, have also come to an estimate of the terms they will offer to execute the work, taking all the usual chances. The chief captain now puts up the various pitches to auction, the biddings being downward. The captain generally names a price above that which ought to be given, and the miners bid downwards against each other, if they please, until the fair price is agreed upon, which is generally nearly understood beforehand, as all parties are fairly aware of what it ought to be. It may happen, indeed, that the miners at work on the spot, just before the setting-day, have discovered appearances which lead them to think that they may take the pitch on apparently low terms, so that they may gain largely by breaking an amount of ores which the captains may not consider probable; but this occurs rarely. The pitches are commonly taken by a number of men proportioned to the work to be executed, but though they often vary from 2 to 12, it is usually contrived that there shall be at least 2 for each spell or core of 8 hours, the usual division of the spells. This partnership is generally termed a *pair* of men, whatever the number may be, and one commonly acts at the setting-days as a bidder for the rest. When no one is disposed to bid lower, the captain flings a pebble to the *taker*, as he is styled, and he is proclaimed, and his bargain entered. It is seldom that the captain fails to find a taker at a fair price, but should he do so, the work is referred to some future setting-day. As soon as the pair is chosen, they are entitled to an advance of money for subsistence, and hence called *'sist-money*, until the period of their taking is completed. The setting-day is a holiday at the mine, and generally occurs every two months. Before proceeding to the business of bidding, the rules are read, and fines attached for breach of regulations.

By obtaining a certain sum in the pound for the ores when sold, the tributers are interested in sending up as much ore to the surface as they can during their occupations in the various pitches, and hence their interests become those of the mine generally. If a pitch should turn out better than was expected, they may gain considerably; but should it become poorer, they suffer loss in proportion. The tributers pay for their coals, candles, and gunpowder; for the use of the machinery by which the ore is raised to the surface; and the wages of those who wash and prepare the ores for sale.

It is not known when this system of *working on tribute* was first introduced. Mr. John Taylor remarks, on the working of this system, that "the mine owners, having by their capital, and the skill of their agents, discovered the ore, formed approaches to it, drained off the water, and ventilated the places for working, admit co-adventurers for a time, whose interest it is not only to search out every piece of ore that can be profitably worked, but so to detach it from the matter with which it is mixed, as to incur the least possible expense in after-processes. The payments they make cause them to look with a jealous eye on all cost incurred by others through whose hands the ores may pass, and thus to tend to a general economy, and perhaps, above all, discoveries are much extended by speculation among the men, who risk their labour only while they bring into play the judgment which the habit of constant observation enables them to form."

Tut-workmen are those who execute work by the piece, generally calculated by the fathom. In this manner shafts are sunk, adits driven, and the labour usually performed in those parts of the mines which do not produce ores, executed. Tut-work is also employed upon the lode itself, though from the advantages generally considered to arise from the tribute system, the latter is employed as much as possible in mines at full work.

Day *labourers* are generally employed on the surface, in dressing ores, and in occupations of the like kind, though in some mines day-labour is also used underground. A large proportion of the surface labourers consists of women and girls.

The comfort of those employed in the mines has of late received far more attention than formerly, and the places where the women and girls pound or pick the ores on the surface, are now nearly always defended from the weather. Barracks are provided for the miners to change their underground clothes, and arrangements are, in some cases, made for drying those which have become wet during work. The miners are liable, from their occupations, to many accidents and diseases, and it is, therefore, usual to provide medical attendance for them, out of a fund raised by the miners themselves. In the deep mines they suffer much from climbing the ladders to the surface, as also from the great changes of temperature experienced in winter, when, after working several hours underground, in a temperature from 70° to 90°, they walk to their homes in the cold.

So extensive are some mines, that it frequently requires an hour to reach the surface, after work is done.[1] The ascent and descent is by ladders, each fifty feet long; which were formerly, and still are in some places, perpendicular to the sides of the mine; but as the mines have been worked deeper, the ladders have been shortened to half that length, and placed as slopingly as possibly, to ease the miner, whose weight is thus rendered more dependent on his feet

(1) The workings of the Consolidated Mines alone extend sixty-three miles underground, or 55.000 fathoms

than on his hands. At the foot of each ladder is a platform, called a *sollar*, with an opening, or man-hole, leading to the next ladder beneath. Considerable attention has been paid in Cornwall to the practicability of providing machinery by which the labour of climbing the ladders may be avoided—a plan which has been successfully adopted in the deep mines of the Hartz. At the Tresavean, the deepest mine in Cornwall, which is worked at a depth of upward of 300 fathoms,[1] a *man-engine*, as it is called, has been erected for raising or lowering the miners, to the depth of 240 fathoms. We will endeavour to explain the principle of this machine. Conceive two rods, A and B, descending the whole length of the shaft, and that from each rod project horizontal stages, or platforms, at distances of 2 fathoms apart, the whole way down. We will call these stages, respectively, A1, A2, A3, A4, &c. and B1, B2, B3, B4, &c. Now, suppose each rod to have a reciprocating motion up and down, through 2 fathoms, and that as one rod is moving upwards the other is moving downwards. When the rods are at rest, the respective stages, A1, B1, A2, B2, &c. coincide. If a man place himself in the stage, A1, and remain there, it is evident that he will be moved up and down through 6 feet, and nothing more; but if when, by the downward motion of the rod A, the stage A1 be brought opposite B2, he step from A1 to B2, he will have descended through 6 feet; and if the rods be so arranged, that when A is at the top of its motion, A is at the bottom, the man now on B2 will be brought opposite A3, and he steps upon it. The next reciprocation will bring A3 opposite B4, and he steps upon that, and thus, upon each shifting of the rods, he is able, with very little exertion, to descend through 6 feet; and what is of even more importance to him, he can ascend without fatigue, and, after some experience, without danger, by similar means, by standing on the lowest step, and when the rod has risen 6 feet, stepping upon the next higher

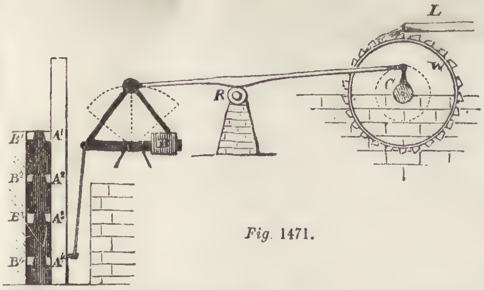


Fig. 1471.

platform on the opposite rod. In Fig. 1471, which is taken from a sketch by Mr. Charles Cochrane, only one rod is represented, the second rod being replaced by fixed steps on the opposite wall of the shaft. As the rod descends, it brings the stage, A1, opposite the fixed stage, B2; the man steps upon this, waits a moment, when the ascent of the rod brings A2 opposite B2, the man steps upon A2, which lowers him to B3, upon which he steps; and in this way he descends as easily, but not so quickly, as in the former case. The rod derives its motion from a crank attached to an overshot water-wheel. The crank is supported on a friction roller, at R, and moves with a balance-bob, at B. The platforms or stages are so arranged as to coincide with the dead points of the crank, so that there is a slight pause at each coincidence of the stages. It is not the least of the many recommendations of this simple but admirable arrangement, that the rods may serve as pump-rods for driving a set of pumps at the bottom of the pit, or a system of pumps at different levels; or for forcing fresh air into the mine and drawing out the foul. Each rod, A or B, when of iron, may be double, like a ladder, with the stages fixed between the pair. There are also guides for maintaining the rods in their vertical position.

In coal pits, or coal and iron pits, the men are lowered down and raised in a rectangular iron frame, called a cage. Two causes of accident pertain to this method;—one is the breaking of the rope, or chain, by which the men are thrown to the bottom, and killed; the other arises from the *overwinding* of the cage, or drawing it over the framing at the pit's mouth, in consequence of the carelessness of the engine-man omitting to stop the engine in time. The result is usually fatal, as the poor miners are thrown down the pit. In the Great Exhibition was a safety bucket, invented by Mr. Robert Blee, of Redruth, and a safety cage, by Messrs. White and Grant, of Glasgow. Inventions of this kind depend upon some such arrangement as the following:—Two pairs of eccentrics are keyed on the ends of two parallel shafts, extending across the top of the cage from side to side: the edges of the eccentrics are toothed, and when the cage is ascending or descending, the eccentrics are free of the vertical wooden guides or rails which steady the cage in its motion up and down the pit. Should the rope slacken or break, two volute springs instantly bring round the thick sides of the eccentrics to bear against the guides, and hold the cage securely. To prevent overwinding, the holdfast which connects the rope to the cage is secured by a curved bolt, which is kept in its place by a strong spring: the bolt moves on a fulcrum, and is continued beyond the holdfast, as a lever: across the framing at the mouth of the pit is a bar, so arranged that when the lever comes in contact with it, the bolt is instantly disengaged, leaving the cage fixed by the action of the eccentrics, while the rope alone is drawn up over the pulley. In Mr. Blee's contrivance the catches allow the cage or bucket to move freely, so long as there is a vertical strain on them; but should this cease, in consequence of the breaking of the rope, the catches are liberated, and secured upon the iron staves of the ladders placed on either side of the shaft.

We cannot conclude this notice without referring to the extraordinary situation of some of the Cornish mines, especially the Botallack mine, represented in a steel engraving, and of which Fig. 1472 gives another view. In the Saint Just district, near the Land's End, the directions of the veins and the dis-

(1) Dolcoath Mine is more than 210 fathoms below the adit-level, which is 30 or more fathoms below some parts of the surface. The main shaft of the Fowey Consols is about the same depth.

tribution of the ores direct many of the mining operations towards the sea. Several of the mines are worked to some extent beneath the bed of the Atlantic, and the breaking of its waves is distinctly audible to the miner whilst at work. In Little Bounds, Botallack, and Wheal Cock, the miners actually followed the ore upwards to the sea; but the openings made were very small, and the rock being extremely hard, a covering of wood and cement in the two former, and a small plug in the latter mine, sufficed to exclude the water. "In all these, and in Wheal, Edward, and Levant," says Mr. Henwood, "I have heard the dashing of the billows and the grating of the shingle overhead, even in calm weather I was once, however, underground in Wheal Cock during a storm. At the extremity of the level seaward, some eighty or one hundred fathoms from the shore, little could be heard of its effects, except at intervals, when the reflux of some unusually large wave projected a pebble outward, bounding and rolling

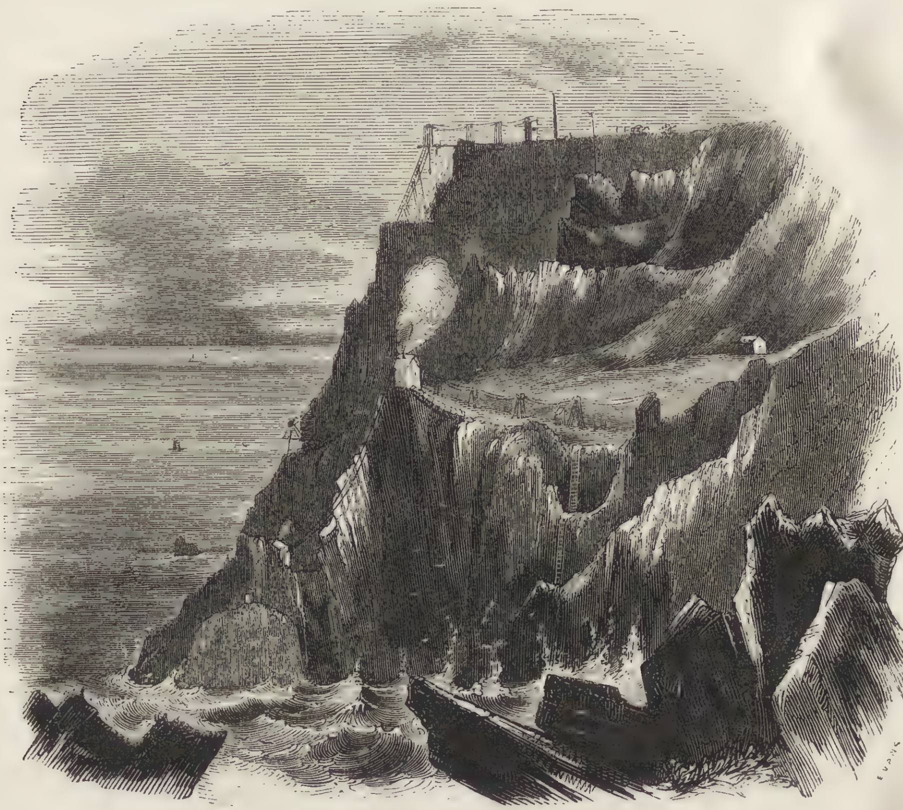


Fig. 1472. EXTERIOR WORKS AT BOTALLACK MINE.

over the rocky bottom. But when standing beneath the base of the cliff, and in that part of the mine where but nine feet of rock stood between us and the ocean, the heavy roll of the larger boulders, the ceaseless grinding of the pebbles, the fierce thundering of the billows, with the crackling and boiling as they rebounded, placed a tempest in its most appalling form too vividly before me to be ever forgotten. More than once, doubting the protection of our rocky shield, we retreated in affright; and it was only after repeated trials that we had confidence to pursue our investigations."[1]

MINERAL WATERS. See WATER.

MINERALOGY is that branch of Natural History in which mineral substances are classified and distinguished, their uses made known, and their modes of occurrence in the earth pointed out. A proper knowledge of minerals cannot be acquired without a knowledge of their chemical composition as well as their external or physical properties. There are substances which are similar in composition but different in physical properties; and there are also bodies which are externally alike, but of very different chemical constitution. In the strictest sense, however, a mineral species is a *natural* inorganic body, with a definite composition, and a regular determinate

(1) In the preparation of this article we have consulted a variety of works, among which may be mentioned Mr. Henwood's papers in the Transactions of the Geological Society of Cornwall, Professor Ansted's Geology, the article Mining in the Penny Cyclopædia, Regnault's Chimie, Ville-Fosse sur la Richesse Minérale, and the Report on the Geology of Cornwall by Sir H. de la Beche, Among our illustrations, Figs. 1458, 1459, 1460, 1465, are from sketches taken by Mr. F B. Miller, of King's College: Figs. 1456, 1457, 1464, 1466, 1470, are from Mr. Cyrus Redding's Illustrated Itinerary of Cornwall, of which the original wood engravings have been placed at our disposal: Figs. 1461, 1462 are reduced from Sir H. de la Beche's Report

form or series of forms. Hence we ought to exclude from the study of mineralogy,—the salts of the chemist, which are *artificial;* air and water, and the inorganic secretions of plants and animals, which have no regular determinate form. Most mineral systems, however, include coal, amber, and mineral resins; as also certain amorphous substances of no precise form or chemical composition, such as some kinds of clay. Aggregates of simple minerals, such as rocks, belong properly to Geology.

Minerals have been classified in various ways, but perhaps the most rational method is that which is based upon their chemical composition. The following classification is by M. Dufrénoy:[1]—

FIRST CLASS.—*Simple substances, each being one of the essential principles of compound minerals.*

Electro-negative bodies; never acting as a base with the bodies of other classes, and always forming a constituent of binary compounds.

Genus.	Genus.	Genus.
I. Oxygen.	X. Silicium.	XIX. Tellurium.
II. Hydrogen.	XI. Titanium.	XX. Mercury.
III. Nitrogen.	XII. Columbium.	XXI. Molybdenum.
IV. Chlorine.	XIII. Sulphur.	XXII. Tungsten.
V. Bromine.	XIV. Selenium.	XXIII. Chromium.
VI. Iodine.	XV. Arsenic.	XXIV. Osmium.
VII. Fluorine.	XVI. Phosphorus.	XXV. Rhodium.
VIII. Carbon.	XVII. Vanadium.	
IX. Boron.	XVIII. Antimony.	

SECOND CLASS.—*Alkaline Salts.*

The different salts composing this class are soluble in water, and possess a marked taste.

Genus.	Genus.	Genus.
XXVI. Ammonia.	XXVII. Potash.	XXVIII. Soda.

THIRD CLASS.—*Alkaline Earths* and *Earths.*

The substances composing this class have a stony aspect; pure, they are without colour or of a milky white; they are not generally hard. With the exception of corundum, none scratch glass; their sp. gr. is between 2·7 and 4·6; tungstate of lime alone forms an exception to this general rule.

Genus.	Genus.	Genus.
XXIX. Baryta.	XXXI. Lime.	XXXIII. Yttria.
XXX. Strontia.	XXXII. Magnesia.	XXXIV. Alumina.

FOURTH CLASS.—*Metals.*

This class comprises two divisions, each distinct in aspect:—

1. Native metals, and the combination of many metals with each other in a metallic state.
2. Combinations of metals with oxygen or with acids.

The minerals of the first division have generally a metallic lustre, which gives them a remarkable external character, distinguishing them from other minerals.

The combinations of the metals with oxygen or with acids rarely present this lustre: in this respect they range among the minerals of the class silicates. They nevertheless, for the most part, possess a peculiar colour, which serves as a guide to their study: their sp. gr. is generally high, and almost all upon assay immediately give a regulus or metallic scoria.

Genus.	Genus.	Genus.
XXXV. Cerium.	XLI. Cadmium.	XLVII. Silver.
XXXVI. Manganese.	XLII. Lead.	XLVIII. Gold.
XXXVII. Iron.	XLIII. Tin.	XLIX. Platinum.
XXXVIII. Cobalt.	XLIV. Bismuth.	L. Iridium.
XXXIX. Nickel.	XLV. Uranium.	LI. Palladium.
XL. Zinc.	XLVI. Copper.	

FIFTH CLASS.—*Silicates.*

The minerals of this class have all a stony aspect, whence they were long known especially as *stones.* They form two distinct groups,—the hydrous and the anhydrous silicates: the first are soft and easily soluble in acids: the second are hard; a portion with difficulty soluble in acids; the greater part insoluble in them.

The sp. gr. of the silicates is between 2·5 and 3·6; a small number only approaching the latter limit.

Genus.	Genus.
LII. Aluminous silicates.	LVII. Non-aluminous silicates.
LIII. Hydrated aluminous silicates.	LVIII. Silico-aluminates.
LIV. Silicates of alumina, of lime, or their isomorphic substances.	LIX. Silico-fluates.
LV. Aluminous and alkaline silicates, and their isomorphic substances.	LX. Silico-borates.
LVI. Aluminous hydrated silicates, with alkalies, lime and their isomorphic substances.	LXI. Silico-titanates.
	LXII. Silico-sulphurets.
	LXIII. Aluminates.
	LXIV. Substances of unknown composition.

SIXTH CLASS.—*Combustibles.*

The minerals constituting this class for the most part present traces of their organic origin: when crystallization has, as in *mellite,* effaced this essential character, we are reminded of it by the nature of the elements which enter into the composition of the mineral.

(1) Traité de Minéralogie, 4 vols. 8vo. Paris, 1844—1847.

The combustibles of organic origin generally burn with flame at a moderate temperature, giving out a marked odour. They are soft; their sp. gr., generally very low, does not exceed 1·6.

They may be divided into the following:—

1. Resins. 2. Bitumens. 3. Fossil combustibles, comprising *anthracite, coal, lignite* and *peat.*

Genus. LXV. Resins.	Genus. LXVI. Bitumens.	Genus. LXVII. Fossil combustibles.

Under these 67 heads are now classed more than 500 minerals, which are supposed really to differ sufficiently to be so separated, independently of many which may be considered as *varieties* or *accidental.*

The characters of minerals are arranged by M. Dufrénoy under the following heads:—

1. *State of aggregation.* Minerals are usually solid; but some, such as native mercury and certain bitumens, are liquid. Minerals may be distinguished as liquid, friable, and solid.

2. *Colour.* Colours are either constant or accidental: when constant and connected with chemical composition they are characteristic; thus peroxide of iron is red, sulphuret of lead a peculiar blue-grey, and so on. Accidental colours are chiefly due to the mixtures of mineral substances. The peculiar appearance known as *chatoyant* depends upon the structure, and is referred to the cleavage planes, the reflected light from which changes according to their position. Labradorite is a good example of this property.

3. *Form.* This character does not refer to the geometric crystalline arrangement, but comprises only *common, imitative, pseudomorphous* and *pseudoregular* forms. The term *Common* is applied to the mode of occurrence of the mineral in *mass, fragments, plates,* or in an *amorphous* condition; Imitative, to its occurrence in *grains, nodules,* &c.; Pseudomorphous, when a mineral takes the form of a pre-existing body, whether organic or inorganic. The term Pseudoregular is applied to such arrangement of parts as are presented by basaltic columns, and other prismatic forms of igneous rocks, apparently also extending to the parallelopipeds arising from the intersection of the divisional plans commonly termed the *joints* and *cleavage* of rocks.

4. *Lustre,* such as *vitreous, waxy, silky, nacreous, adamantine, semi-metallic* and *metallic.*

5. *Hardness.* Minerals are compared with the following scale:—

1, Lamellar Talc; 2, Selenite; 3, Iceland spar; 4, Fluor-spar; 5, Phosphate of lime; 6, Lamellar felspar; 7, Rock crystal; 8, Topaz; 9, Ruby, or Sapphire; 10, Diamond.

8. *Toughness,* or the resistance which a substance offers to be broken or torn. A soft mineral may be very tough, such as sulphate of lime; a hard one readily fractured, as flint; and some minerals are both hard and tough, as jade.

9. The *Scratch.* Trials for hardness give a scratch and powder, which are useful in the determination of minerals. Thus the ores of iron, named *hematites,* give a red or yellow ochre powder, which distinguishes this mineral from the concretionary ores of manganese, the powder of which is black.

10. The *Stain.* This character applies to a few soft minerals only. It consists in marking paper or linen with the mineral: chalk and plumbago are examples. Plumbago may be thus distinguished from sulphuret of molybdenum, which it otherwise much resembles.

11. *Unctuosity.* Many minerals are *soft* and *soapy* to the touch, such as talc and serpentine, magnesian minerals.

12. *Flexibility.* Several minerals are flexible, such as native silver and copper. Some are both flexible and elastic, as mica.

13. *Ductility* is chiefly applicable to native metals. Although sulphuret of silver and halloysite cannot be lengthened under the hammer, they are nevertheless termed *ductile* by the mineralogist.

14. *Taste* is only applicable to certain substances, distinguished as *bitter, sweet, salt,* &c.

15. *Adhesion to the tongue* is generally sufficient for distinguishing argillaceous from pure limestones.

16. *Odour,* such as, of the bitumens and other similar substances, or that obtained by breathing on, or rubbing a mineral, when a peculiar odour is perceived.

17. *Cold.* The sensation of cold when a mineral is placed in the hand. Thus rock crystals and gems can be distinguished from glass and enamels, which otherwise may be made closely to imitate them.

18. *Sound.* Some substances are very sonorous: phenolite is named from this property.

19. *Weight,* as perceived by weighing a mineral roughly in the hand; carbonate of lime, sulphate of baryta, and carbonate of lead, may be readily distinguished in this way.

With respect to the crystalline types, the following is Dufrénoy's arrangement, founded on that of Haüy:—

With perpendicular axes:—

I. *Cube,* the modifications of which are the octahedron, the regular rhomboidal dodecahedron, the hexatetrahedron, the trapezoihedron, the octotriahedron, and some other forms.

II. *Right prism with a square base,* the modifications of which are the octahedron with a square base, the dioctahedron, and others.

III. *Right rectangular prism,* the modifications of which are the right rhomboidal prism, the rectangular octahedron, the rhomboidal octahedron, &c.

With oblique axes:—

IV. *Rhombohedron,* including equiaxial rhombohedrons, scalene triangular dodecahedrons, two regular prisms with six faces, and isosceles triangular dodecahedrons.

V. *Oblique rhomboidal prism,* with its modifications.

VI. *Non-symmetrical oblique prism,* with its modifications.

MINIUM. See Lead, page 116.

MINT. See Coining.

MIRROR. See GLASS, Sec. VIII. Metallic mirrors, or specula, are noticed under CASTING and FOUNDING.

MISPICKEL, or arsenical pyrites, an abundant source of arsenious acid. [See ARSENIC.] It appears to be a compound of bisulphuret of iron and arsenuret of iron, $FeAs,F_2S_2$. It occurs native in many parts of Europe. It is of a more silvery colour than iron pyrites, and when heated exhales arsenic.

MODEL. When a man of mechanical genius has invented a machine for the performance of some kind of work, which had previously been done by manual labour; or when by rearranging the parts of an old machine, and introducing new combinations, he invents what is in effect a new machine, his first trials as to the efficiency of his invention are generally made with models, and he is usually satisfied that if the model answer his expectations, the full-sized machine is likely to be perfectly successful.

There are reasons which tempt an inventor to construct a model and to rely on the results which are obtained by its means. A model may be easily constructed at no great cost, while the full-sized machine may be very expensive, and may occupy a large amount of space. It also does at first sight appear, that a well-constructed model is a perfect representation of the arrangement and proportion of the different parts of a machine and its mode of action, and that the performance of the model is commensurate with that of the machine. But it is nevertheless true, that a machine may act perfectly well on a small scale, but fail when enlarged.

An inventor seldom pauses to inquire into the relation subsisting between the model and the full-sized machine. He does not often ascertain what effect a change of scale has on the strength and on the friction of a machine. He may not sufficiently consider, that when he enlarges the scale on which a machine is constructed, its surface and bulk are enlarged in much higher ratios. If the linear dimensions of a machine be all doubled, its surface will be increased fourfold, and its solidity eightfold. Were the linear dimensions increased tenfold, the superficies would be increased 100, and the solidity 1,000 times.[1]

All machines consist of movable parts sliding or turning on others, which are bound together by bands, or supported by props. Now, first, as to the frame-work. In the case of a prop, destined to sustain merely the weight of some part of the machine, the strength is estimated by so many cwts. per square inch of cross section. If, in the model, the strength of the prop be sufficient for double the load put upon it, and the scale on which the model was constructed be enlarged tenfold in the construction of the machine, the strength of the prop would be augmented 100 times: it would be able to bear 200 loads of the model; but the weight to be put upon it would actually be 1,000 times that of the small machine; so that, in fact, the prop in the large machine would be able to bear only $\frac{1}{5}$th part of the load to be put upon it: it would in fact fall to pieces by its own weight.

We see, then, in this case, how inaccurately the model represents the performance of the larger machine. It is evident that the supports of small objects ought to be proportionally smaller than those of larger ones; and we see how beautifully Nature changes her proportions at each change of size. If the proportions of an elephant were given with the size of a mouse, the limbs would be too strong and unwieldy; and if a mouse were enlarged to the size of an elephant, its limbs would be totally unable to sustain the weight of its body.

The same principle will apply to bodies in a state of distension. Suppose, for example, the chains of a suspension-bridge were computed to bear 9 times the load put on them, and that a similar structure were formed of 10 times the linear dimensions, the strength of the new chain would be 100 times greater, while the load put upon it would be increased 1,000 times, so that the new structure would possess only $\frac{9}{10}$ths of the strength necessary to support itself. Hence how little important it is to show that a model of a bridge, constructed on a scale of probably 1 to 100, will support its own weight, since the weight of the enlarged chain would have torn itself to pieces, supposing it could even have been raised. It is stated, that the larger spiders spin threads much thicker in comparison with the diameter of their own bodies than those spun by smaller ones.

When a beam gives support laterally, its strength is proportional to its breadth and to the square of its depth conjointly. If such a beam be enlarged 10 times in each of its linear dimensions, its ability to sustain a weight placed at its extremity would, on account of the increased distance from the point of insertion, be increased only 100 times, while the load to be put upon it would be increased 1,000 times; and thus, although the parts of the model may be quite strong enough, it does not follow that those of the enlarged machine will be so.

It will be seen, from these illustrations, that in similar machines the strengths of the parts vary as the square, while the weights to be placed upon them vary as the cube of the corresponding linear dimensions.

This general principle ought to be carefully attended to by machine-makers when a change of scale, however small, is to be made; for by attention to it they will conduce to the sufficiency or economy of the structure. To enlarge or diminish the parts of a machine in the same proportion is clearly wrong. Enlarge a midge until its whole weight is equal to that of a sea-eagle, and great as the enlargement is, its wing would scarcely be equal to the thickness of writing-paper. It should be remembered that the larger animals are not supported laterally, their limbs being always nearly vertical; as we descend in the scale of size, the lateral support becomes more frequent, until we arrive at whole classes of insects

(1) This mode of viewing the subject, and the general reasonings and illustrations in this article, are from a paper by Mr. Edward Sang, "On the relation which subsists between a machine and its model," read before the Society of Arts for Scotland, and inserted in Jameson's Edinburgh New Philosophical Journal for 1833.

which rest on limbs placed in nearly a horizontal position.

Having thus noticed the relative strengths of a machine and its model while at rest, let us compare their relative strengths and actions when in motion. This subject may be considered under two heads, the *one* relating to the ability of the structure to resist the blows given by the moving parts, either in their ordinary action, or when by accident they escape from their usual course; the *other* relates to the changes which take place in the friction of the parts when enlarged or diminished.

The ability of a support to resist the impetus of a moving body, is estimated by combining the pressure which it is able to bear with the distance through which it can yield before it breaks. In the case of a support which acts longitudinally, the strength is proportional to the square of the linear dimension, while the distance through which it can yield is as the linear dimension itself. Altogether, then, the ability to resist a blow is proportional to the cube of the length; that is, to the weight of the body which is destined to act upon it. If, then, the linear velocity of the machine is to be the same with that of the model, these parts, as far as this action is concerned, will be in keeping with each other.

In the case, however, of a lateral support, the distance through which it can yield without breaking is not augmented by an enlargement of the scale; so that in these parts, the large engine is comparatively weak, even though the velocity of the motion be the same on the large as on the small scale.

But those motions which are most likely to produce accidents in this way, are generated by descents, which bear a fixed proportion to the dimension of the engine. The velocity, therefore, is generally greater in the large engine than in the small one, so that large machines are more liable to accidents arising from the derangement of any of their motions than small ones: they possess, however, more absolute strength, and are better able to resist any extraneous force. But we must carefully distinguish between the absolute strength of any structure or the power which it has of resisting impressions from without, and the ability of that structure to withstand the effects of derangement among its own parts.

When we consider its ability to resist mere pressure, or its ability to resist an impulse, the performance of an engine is not at all commensurate with that of its model. As great a disparity is perceived, when we consider the friction of the parts. For example, "the steam-engine moves on account of the pressure of the steam against the surface of the piston, which pressure may be estimated at about 10 lbs. per circular inch. The friction which this pressure has to overcome, may be divided into three parts: the first including all friction caused by the packing of the piston and stuffing-boxes, and which is proportional to the linear dimension simply; the second including that part of the friction on the gudgeons which arises from the pressure of the steam upon the piston, and all other friction proportional to the square of the linear dimension; and the third including all that friction which arises from the weight of the parts, and which is thus proportional to the cube of the dimension. Suppose that in an engine whose cylinder is 20 inches across, and whose inciting pressure will thus be 4,000 lbs., the friction of each kind is 100 lbs., the entire friction being thus 300 lbs., or about $\frac{1}{13}$th part of the moving force. From this model let us construct an engine on the enlarged scale of 20 to 1. The new cylinder will be 4,000 inches in diameter, and the pressure on the piston 1,600,000 lbs. The friction of the first species would amount to 2,000, that of the second to 40,000, and that of the third to 800,000 lbs., so that the sum total of the friction, no less than 842,000 lbs., would be fully more than half of the inciting pressure. It is, then, clear that such an enormous engine would be highly disadvantageous as a mechanical agent, and that if the enlargement were pushed a little further, the whole of the moving force would be expended in overcoming the friction. There is, then, a greatest size, beyond which it is impossible to proceed in the construction of the steam-engine. But there is also a least. Let us take an engine similar to our first, but with a cylinder of only 1 inch in diameter. In such an engine, the pressure of the steam upon the piston would be only 10 lbs.: the three kinds of friction would amount respectively to 5 lbs., 1 gr., and 1-80th part of a pound; the first kind alone being equal to half the inciting force. Were the diminution still further continued, the friction of the packing of the piston might equal the pressure of the steam. From this it is apparent, that for each shape of steam-engine, there are two extreme limits as to size, at which the utility of the engine ceases altogether, and between which there is placed a best size, or one which is accompanied by the most complete development of the powers of the engine. A skilful arrangement of the parts may, indeed, extend the limits both ways, and may thus change considerably the most advantageous size; yet even with that assistance, very small or very large engines are less productive of force, in proportion to the quantity of coal they consume, than moderately sized ones are; and in many instances, it would have been better to have employed two or three middle-sized engines, than a single one possessed of two or three times the nominal power."

In conclusion, then, it may be stated that every instrument, whether it be used for the generation or for the transference of power, has a best size, and a best form: that security demands strength, strength requires weight, weight increases the friction, the friction calls for additional power, and power can only be procured by an increase of weight. To reconcile these conflicting claims, is not a task for a beginner in mechanical contrivances, but for one well versed in the theory and in the practice of the arts. Models have only a limited use, for although they may perform well, that is no guarantee for the successful performance of the full-sized machines.

MODELLING, an art which depends almost entirely on the skill, taste, and manipulation of the operator, and is nearly independent of tools.

Modelling tools are either loops of wire of different sizes fixed in wooden handles, or variously shaped pieces of ebony or box-wood. Both are to be considered merely as occasional aids to the fingers, or to be used in portions of the work which the latter cannot reach. The wire tools are convenient for removing portions of clay by drawing the wire under them, and so leaving the adjacent parts undisturbed. The clay thus severed remains adhering to the model until its own weight causes it to fall, or until it is gently removed by the operator. These tools also assist the modeller in producing concave surfaces, narrow folds of drapery, &c., the wire being sometimes notched where a rough effect is required. The wooden tools may be sharp-pointed or blunt, straight or curved, flat or round, narrow or broad. The broad tools assist the formation of large convex surfaces, and the more ample folds of drapery. Wooden tools for fine work are generally kept soaked in oil to prevent the clay from adhering to them.

The material used in modelling, is common potter's clay of the best quality, made so wet, that a mass of it will not stand much higher than its own width without support. It is necessary throughout the various stages of the work, that the moisture should be sustained as nearly equal as possible, and that means should be used to prevent the model from drying during the night, or when it is not under the operator's hands. This is not difficult to accomplish, for while the figure is exposed and in progress, it can be frequently sprinkled with water by means of a plasterer's brush, and when it is laid aside for the night, the moisture can be sustained by means of a wet sheet wrapped around it. Another way of preserving the moisture for a considerable time without adding water, is to draw over the model an air-tight case or bag, and to make the same fast with clay to the plinth. A very wet state of the clay in modelling, causes the clay to adhere more to the tools, but at the same time greatly facilitates the proceedings of the modeller, and saves his time.

During the progress of the work, careful and sufficient support must be given to the model, or after all the labour of the artist, it may fall to pieces when it is finished. In modelling a bust, the only support required is an upright piece of wood with a cross-bar at the shoulders; but for a full length figure, especially if in any unusual attitude, the nature of the supports requires the most minute and careful attention. Figures of the ordinary size are generally modelled upon a bench or stand called a *banker*, $2\frac{1}{2}$ feet high, and $2\frac{1}{2}$ feet square; above this a solid circular plinth is fixed on a wooden boss, and turns upon 6 or more wheels, or preferably, upon short slightly conical rollers, fixed to the plinth near the circumference. A revolving plinth is necessary to enable the sculptor to view his work in all directions, and in any light, and to work on it in the most favourable position. On the centre of this revolving plinth, is fixed a strong iron bar the height of the intended figure, and from 6 to 10 inches in circumference. This is to be the main support of a skeleton-work of other supports, for the protection of the limbs, draperies, &c. At the shoulders and loins two cross-pieces of wood are fixed to the main bar, from which the supports of the arms and legs are projected; sometimes it is desirable to have a third cross-piece, midway between the two others, for the better support of the clay. The supports of the legs consist of stout bars either straight or bent, according to the position of the figure; those of the arms, when not detached from the body or drapery, may be made of twisted thick copper wire, with short pieces of wood at intervals twisted in with the wire, and at right angles, like the pieces of paper in the tail of a kite. The fingers, if separate, will also each require separate support. The entire skeleton of supports must be so strong and unyielding as not to give way in any degree under the mass of clay that is to be built up against it. The construction of such a skeleton, therefore, requires an experienced and able hand, and will take many days of labour. A novice in the art would always do well to get the supports for his early works constructed by an experienced person.

A model should always be made of the size of the intended figure, for although there are facilities for increasing the scale at pleasure, yet it is found that trifling errors in a small model become multiplied in the larger one to such a degree as to give the artist much after labour. In former days, the sculptor, on the completion of his model, adopted the cheap and easy method of baking it in an oven. These baked models, called *terra cotta*, or baked earth, were usually of small size, and are extremely numerous, but there are also a few of large dimensions preserved in museums. There is, however, a great objection to this plan; namely, the shrinking, and sometimes the cracking of the clay under the influence of heat. The present method is to take a plaster cast, from which to work the marble or to take other casts. The whole model, while wet, is covered in two or three or more masses with plaster-of-Paris, and when this is well set and dry, the whole may be separated without any regard to the preservation of the original model, for when the mould is obtained, the model is no longer wanted. All the clay being completely removed from the mould, and the parts of the mould put together again, plaster-of-Paris is poured in until the mould is filled. After allowing a proper time for drying, the mould is carefully broken off in fragments, and the perfect cast exposed. Supposing other casts to be required, another mould, called a *safe-mould*, must be made in many parts; and if the figure is to be executed in marble, it must be copied by means of the pointing-machine. See SCULPTURE.

MOHAIR, the hair of a goat in the vicinity of Angora, in Asia Minor. See WEAVING.

MOIREE METALLIQUE. See TIN.

MOLASSES. See SUGAR.

MOLYBDENUM (Mo 48), a rare metal found in

the form of a sulphuret, from which molybdic acid was first prepared by Scheele in 1778, and from the acid the metal was obtained by Hielm in 1782. The acid must be intensely heated in a crucible lined with charcoal. The metal is white, brittle, and very infusible. Its density is 8·6: it oxidises when heated in the air, and forms molybdic acid MoO_3.

MOMENTUM. See STATICS and DYNAMICS.

MONTGOLFIERE. See AEROSTATION.

MORDANT. See DYEING—CALICO PRINTING.

MOROCCO. See LEATHER.

MORPHIA or MORPHINE. See OPIUM.

MORTAR. See TRITURATION.

MORTARS and CEMENTS. Mortar is a substance placed between stones and bricks for the purpose of cementing them together. It consists essentially of lime and siliceous sand, the lime being in the state of hydrate. The sand used is of different degrees of fineness, from river or pit sand up to coarse gravel, which latter, being mixed with the lime or mortar, forms what is called *concrete*. When the lime which is used in making mortar has been prepared from a limestone containing *clay*, or argillaceous matter, in certain proportions, the mortar possesses the property of setting or solidifying under water: such a lime is termed *hydraulic lime*, and the mortar made from it *hydraulic mortar*. Mortars of this kind are often termed *cements*, without any very sufficient reason, since every kind of mortar is properly a cement. Hydraulic mortars are also prepared with lime and certain volcanic productions, known as *puozzolano*, and *trass*, and even certain products of artificial calcination, such as bricks, tiles, coarse pottery, cinders, furnace slag, &c.

But as the basis of mortars and cements is lime, we propose first to consider, at some length, the industrial methods of preparing this important substance. A variety of particulars respecting lime, or its carbonates, are given under LIME, MARBLE, CARBONIC ACID, and it is to the carbonates of lime that we must now direct attention.

Pure carbonate of lime, CaO,CO_2, occurs native in calcareous spar and a few other minerals; but most of the calcareous rocks contain other ingredients in addition to carbonic acid and oxide of calcium: these ingredients are magnesia, oxide of iron, manganese, clay, bitumen, quartzose sand, &c. The term *limestone* is applied to those stones which contain at least one-half of their weight of carbonate of lime; and according to the other prevailing ingredients a limestone may be *argillaceous, magnesian, sandy, ferruginous, bituminous, fetid*, &c. These varieties are further distinguished according to their forms and texture, as *lamellar, saccharoid, granular, compact, oolitic, chalky, pulverulent, concreted*, &c. Now the lime obtained from one or other of these stones varies in quality, colour, weight, avidity for water, and the degree of hardness which it assumes when made into mortar.

Lime is prepared from limestone by the action of heat in kilns, arranged so as to deprive the limestone of its carbonic acid, as completely as possible, in the shortest time, with the smallest quantity of fuel, and with the least amount of labour.

Lime-kilns are variously constructed, according to the method of working them, and the kind of fuel to be used. In places where materials are expensive on account of their carriage, and where the fuel is coal, the form of kiln is generally that of an inverted cone; but this form is not considered by practical lime-burners to be equal to the elliptical, or ovoidal, the latter resembling the form of an egg placed upon its narrow end, with part of its broader end struck off and its sides somewhat compressed, especially towards the lower extremity; the ground plot, or bottom of the kiln, being nearly an oval, with an *eye* or draft-hole towards each end of it. The advantages of this form over the cone are, that, by contracting the upper part of the kiln, the heat does not escape so freely as it does out of a spreading cone, but is reflected back upon the materials. Another advantage is, that when the cooled lime is drawn out at the bottom, the ignited mass in the upper part settles down evenly into the central part of the kiln; whereas, with a conical form, the regular contraction in width prevents the burning materials from settling uniformly: they hang upon the sides, and either form a dome at the bottom with a void space beneath it, endangering the structure, if not the workmen; or, breaking down in the centre, form a funnel, down which the unburnt stones find their way to the draft-holes. The contraction of the lower part of the kiln has not the same effect, for when the fuel is burnt out the mass loosens, and as the lime cools it occupies less space, and runs down freely to the draft-holes.

The oldest kiln is probably that produced by excavating the earth in the form of a cone, and building up the sides, if necessary. Alternate layers of fuel and stone properly broken are then laid in, until the whole is filled up. The top is covered with sods, to prevent the loss of heat: the fire is lighted at the bottom. The sides of such a kiln, which is called a *sod-kiln*, are sometimes lined with sods. When the fire has burnt out, and the contents are cold, they are drawn out from the bottom, and the kiln is again filled. A superior kiln of this kind as used in the neighbourhood of Lille, is shown in Fig. 1473. It is charged with alternate layers of coal and limestone, in the proportion of 4 measures

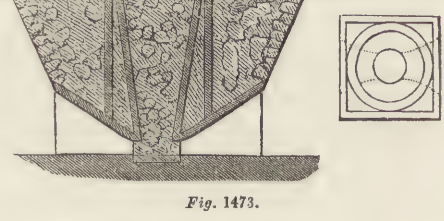


Fig. 1473.

of limestone to 1 of coal or 1½ of coke. The coal is wetted before being used. When the calcination is complete, which is known by the subsidence of the mass, and the flame at the top being nearly destitute

of smoke, about two-thirds of the contents of the kiln are extracted at the bottom, and the empty space gradually filled up with alternate layers as before. Where lime is constantly required in large quantities, the operation is made still more continuous in what are called *draw-kilns* or *running-kilns*. These may be situated by the side of a rising bank, or sheltered by an artificial mound of earth. They may be of stone or of brick; the latter being often preferred, as being better calculated to withstand the heat. The outside form of such kilns may be cylindrical or square. The interior is in the shape of a hogshead, or an egg opened a little at both ends, and set on the smaller. Near the bottom, two or more openings are made; these are small at the inside of the kiln, but widen out as they extend to the outside. These holes supply air to the furnace, and allow the labourers to approach with a drag and shovel to draw out the burnt lime. Within the kiln, at the bottom, a wedge-shaped projection, Fig. 1475, called a *horse*, is sometimes formed, to assist the drawing out of the lime by directing it towards the apertures. Or instead of this, there may be an iron grate near the bottom, coming close to the inside wall, except at the apertures where the lime is drawn out. When the kiln is to be charged, a quantity of furze or fagots is laid at the bottom, over this a layer of coals, then a layer of limestone in pieces about the size of a man's fist, and so on alternately, ending with a layer of coals, which may be covered over with turf to retain the heat. The fire is lighted at the apertures, and when the limestone at the bottom is well burnt, that at the top sinks down. The men then add limestone and coal at the top, and draw out at bottom as it is burnt. In this way, large quantities of lime may

Fig. 1474.

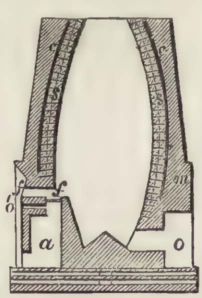


Fig. 1475.

be produced in a short time. When coal is used, three bushels or more of calcined limestone are produced for every bushel of coals consumed.

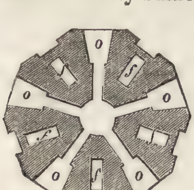
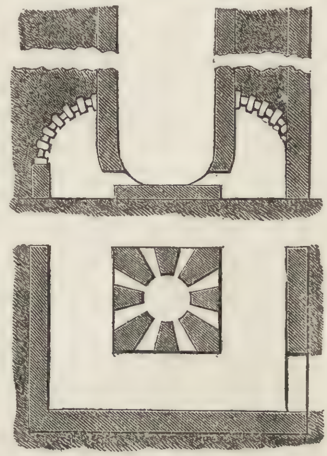


Fig. 1476.

A kiln of this kind, adapted for burning one part wood and four of turf, as used at Rudersdorf, in Prussia, is shown in elevation, vertical section, and plan, Figs. 1474, 1475, 1476. This kiln has five fires, *f f*, distributed round it: *a* is the ash-pit, closed by a door; *o* openings for regulating the draught; *o* larger openings for drawing the lime. It will be seen by the section, Fig. 1475, that the kiln is lined with a double shirt of fire-bricks, *s*, between which and the masonry, *m*, is a space, *c*, filled with cinders well rammed, by which arrangement the heat is prevented from escaping.

Figs. 1477, 1478, represent a continuous kiln used in Belgium, and capable of producing lime in enormous quantities. The kiln is charged with alternate layers of coal and limestone in the proportions used for the kiln, Fig. 1473, and when once the kiln is at the proper heat, lime can be constantly withdrawn from the eight openings at the bottom one after the other, while fresh portions of the charge are constantly added at the top. When the supply of lime is satisfied for a time, the bottom openings are stopped up, and the top is covered with stones and clay, and in this condition the whole mass will remain incandescent for more than 8 days. Once a-year the kiln is allowed to cool, for the purpose of inspection and repairs.



Figs. 1477, 1478.

A lime-kiln constructed by Count Rumford deserves notice. Its objects are, 1. To cause the fuel to burn so as to consume the smoke, which is made to descend and pass through the fire; 2. To cause the flame and hot vapour from the fire to come in contact with the limestone by a very large surface, which is done by making the body of the kiln in the form of a hollow truncated cone, and very high in proportion to its diameter; and by filling it quite up to the top with limestone, the fire being placed near the bottom of the cone; 3. To make the process continuous, and thus prevent loss of heat by putting out and relighting; 4. To cause the lime which is properly burnt and fit for withdrawing to give off its heat into the kiln, so as to assist in burning the fresh stone which may be added. In this kiln, the fuel is not mixed with the limestone, but is burnt in a close fireplace, which opens into one side of the kiln some distance from the bottom. In large kilns there may be several such fireplaces, opening into the kiln on different sides. At the bottom of the kiln is a door for taking out the lime. When a portion of the lime is withdrawn, the contents of the kiln settle down or subside, and fresh limestone is added at the top, and the door is nearly closed with moist clay. As the fire enters the kiln at some distance from the bottom, and as the flame rises as soon as it enters this cavity, the lower part of the kiln, or that below the level of the fire, is occupied by lime already burned, which being intensely heated, radiates its heat upwards, and thus assists the

fire in burning the fresh limestone. To assist this action of the red-hot lime, air is allowed to enter by a small hole in the lower door, by which means a current of highly heated air is brought into contact with the fresh limestone. The height of the kiln may be 15 feet; its internal diameter 2 feet below and 9 inches above. In order to confine the heat, the walls, which are of brick, and very thin, are double, and the cavity between them filled with dry wood-ashes. The two walls are connected in different places by horizontal layers of brick, for the sake of strength. *o* is the opening by which fuel is introduced: it is covered by an iron plate moving on hinges, which plate being lifted up more or less by means of a chain, serves as a register: *o′* is an opening in the front wall of the fireplace, for cleaning it out, and also for allowing the flame to pass from the fireplace into the kiln. This opening must not be entirely closed, as it admits a small quantity of air horizontally into the fireplace, and facilitates the combustion of the smoke. Several small holes for this purpose, fitted with conical stoppers, may be made in different parts of the front wall of the fireplace. The bottom

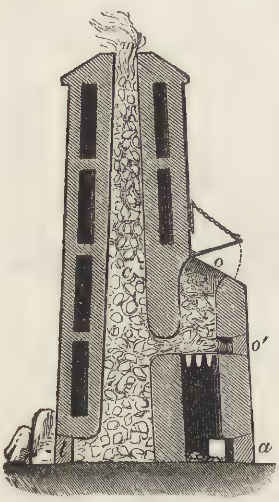


Fig. 1479.

of the fireplace is a grate, constructed of bricks placed edgeways, and under the grate is an ash-pit, the door of which *a* is kept constantly closed (except for removing the ashes), to prevent air from passing through the grate into the fireplace: *l* is the opening by which the lime is taken out; and in order that no more lime may be removed than that which occupies the space below the level of the fireplace, a pit of the same dimensions may be placed near the door, for the purpose of measuring the lime. While the lime is being removed, fresh limestone is added at the top, the fire being damped meanwhile by closing the iron plate. At other times the fire may be further damped, if required, by placing a flat fire-stone or plate of iron more or less over the top of the kiln.

In places where furze is used for burning lime, *flame-kilns*, as they are called, are constructed. They are of brick, with the walls from 4 to 5 feet thick, unless they can be supported by a mound of earth. The interior is 12 feet by 13, and the height 11 or 12 feet. In the front wall are three arches, each about 1 foot 10 inches wide by 3 feet 9 inches high. When the kiln is to be filled, the largest pieces of limestone are built up in the form of arches, the whole breadth of the kiln, and opposite to the arches in the front wall. The remainder of the limestone is then thrown into the kiln, to the height of 7 or 8 feet, over which are frequently laid 15,000 or 20,000 bricks, which are burnt with the limestone. When the kiln is filled, the three arches in the front wall are filled up with bricks nearly to the top, space being left in each sufficient for putting in the furze in small quantities at a time, so as to maintain a constant flame. In about 36 or 40 hours the limestone, about 120 or 130 quarters, together with the bricks, are properly calcined. Fig. 1480 represents an intermittent kiln of a truncated ovoidal form, the space K being about 15 feet high, 10 feet in diameter in the middle, 5 feet at the top, and about 7 feet at the bottom. Air for feeding the fire passes along the channel *v*, and up the small opening *o*: *h* is the opening for the fuel.

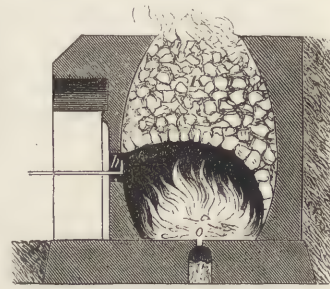


Fig. 1480.

A better form of furnace on this principle is shown in Figs. 1481, 1482. This furnace is constructed of rough masonry, and lined with a shirt of fire-bricks. In charging the furnace, the larger fragments of limestone are built

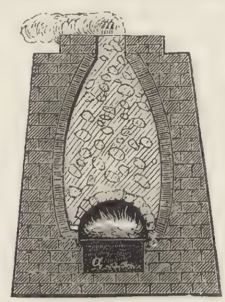


Fig. 1481.

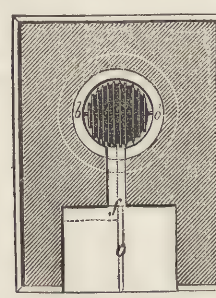


Fig. 1482.

up into the form of a vault, supported by the abutments *b b*. This vault supports the rest of the charge, which is thrown in at the top, care being taken to arrange the large pieces in the middle, the smaller ones near the sides, and to fill up with the smallest fragments. A turf fire is lighted upon the grate *b b*, which is made of moveable bars, and the fire door as well as the door of the ash-pit *a* are closed. The fire is supplied with air by a small opening or channel *o*, and is left for 10 or 12 hours, during which the limestone is blackened by the smoke, and gradually heated; the fire is then gently urged until the charge about one-third up is raised from a red to a white heat. When the mass has subsided, and the flame escapes at the top without smoke, the operation is finished. In this kiln 2 volumes of turf suffice for the calcination of 1 volume of limestone.

In some parts of Scotland and other places where coal is dear, limestone is burnt with peat in alternate strata of limestone and peat in kilns formed of turf; but the quantity of ashes produced by the peat injures the quality of the lime, and the waste of fuel is con-

siderable. But the more common method is to construct peat kilns similar to those in which furze is used, only there are but two arches or fireplaces, and the peats are thrown in at the bottom: the front is seldom closed up, so that there is too much draft, and the limestone is not properly calcined. This is remedied by placing an iron grate across the bottom of the arch with an ashpit below, and closing the front of the arch by an iron door.

A form of kiln invented by Mr. Booker of Dublin, consisted of two long narrow truncated cones placed end to end; the diameter was 7 feet in the middle, and 3 feet at the top and at the base; the height 25 to 30 feet. The top was furnished with a cast-iron cap or cover turning on a pivot: this served to regulate the heat. This kiln was greatly improved by C. J. Stuart Menteath, Esq. of Closeburn in Dumfries-shire. Mr. Loudon, in his Encyclopædia of Cottage, Farm and Villa Architecture (1842), declares it to be the best lime-kiln he had ever seen or heard of. The best situation for this, or indeed for most other forms of kiln, is the face of a steep bank;

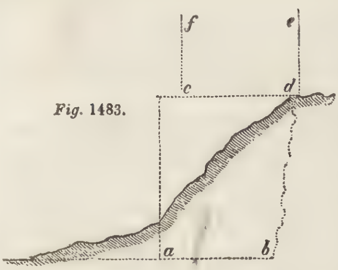


Fig. 1483.

but if this cannot be obtained, it may be constructed on a level surface with a ramped road or incline, or with a mechanical lift for conveying the materials to the top of the kiln. Fig. 1483 is a section across a bank on the face of which the kiln is to be built. *a b c d* indicate the space to be occupied by the kiln, and *c d e f* the situation of the shed over the mouth. Fig. 1484 is a ground plan, in which *h* is the fuel chamber, 2 feet square, with

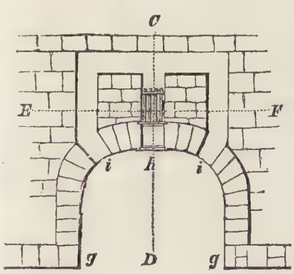


Fig. 1484.

iron bars across: two air openings *i i* at the side may be more or less closed by stones: *g h g* is the space for the cart when loading with the lime as drawn out of the kiln. Fig. 1485 is a horizontal section of the kiln at the height of 18 feet from the grating of the fuel chamber, or on the line A B of Fig. 1488. Fig. 1486 is a plan of the top of the kiln

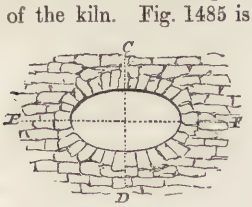


Fig. 1485.

covered by the shed. In this plan *k k k* are the 3 circular openings in the covering arch, through which the broken stones and fuel are introduced; these holes may be covered with iron plates or valves: *l* is the place for the fuel, and *m* for the limestone, the cart for conveying these materials passing in at one

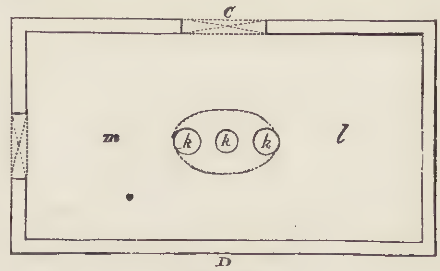
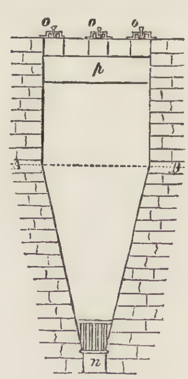


Fig. 1486.

door and out at the other. Fig. 1487 is a vertical section of the kiln, on the line E F, in which *n* is the side opening to the back of the fuel chamber; *o* cast-iron covers, with openings in the centre and lids over them, to the feeding apertures, and *p* the springing of the covering arch. Fig. 1488 is a transverse section of the kiln and shed on the line C D, in which *q* is the fuel chamber; *r* the space between the double doors of this chamber; *s* the covered area on which the loading carts stand; *t* the cast-iron cover to the feeding aperture, and *u* the cover to the chimney of the kiln shed. The walls are of fire-brick or



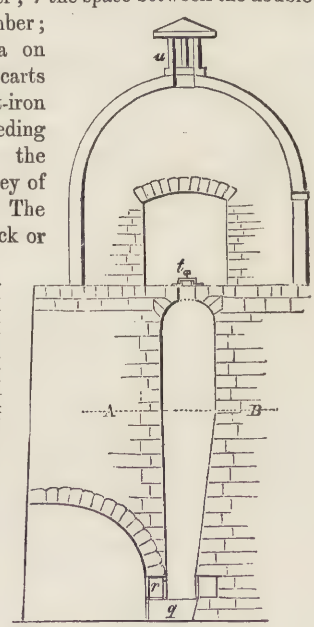


Fig. 1487. *Fig.* 1488.

fire-stone, or even of burned limestone of the same quality as that burned within, only in large masses to prevent their being so much affected by the heat. The upper part of the kiln may be arched over or covered with cast-iron joists and flagstones, with square or oblong holes for the admission of air, and covered with a plate of cast-iron for the regulation of the draught. The shed over the mouth of the kiln is of great use, not only in keeping the materials dry, but in heating them before they are thrown into the kiln. The double iron doors to the fuel chamber should be from 9 to 12 inches apart; but single doors will suffice for the ash-pit. The side openings for the admission of air may be more or less blocked up with stones, to save the cost of iron doors. The bars of the grating

of the fuel chamber may be 2½ feet long, 2 inches wide and 3 inches deep, cast hollow: and the two cross bars on which they rest may be 3 inches broad and 5 inches deep, also cast hollow. The metal need not in either case exceed ¼ inch in thickness: the current of air passing through the hollows contributes to the durability of the bars. The opening behind the fuel chamber for the admission of an extra supply of air is furnished with a grating, where it enters the fuel chamber to prevent its being choked up by the lime either during the burning or the drawing. Mr. Menteath states that a kiln in which coke is the fuel yields nearly one-third more calcined lime, or *shells* as it is termed in Scotland, in a given time than one in which coal is the fuel.

The time required for burning lime depends greatly on the size of the pieces of limestone, their density and state of dryness. The time will be shorter when the stone is not dense, when the lumps are small and have a certain degree of moisture. This is so well known to lime-burners that they are accustomed to water the stone just before burning, unless they can use it fresh from the quarry. The action of the water in facilitating the escape of carbonic acid from the limestone is not very clear: it may be simply molecular, or the water may for a short time take the place of the carbonic acid, and form a hydrate which is itself decomposed as the heat increases; or the water may be decomposed by the fuel, and the resulting hydrogen and oxygen react in several ways upon the carbonic acid; one result would be the production of carbonic oxide, which, being inflammable, would assist in expelling carbonic acid from the limestone. It must also be remembered that in those limestones which contain clay, silica, magnesia, oxide of iron, &c., these substances tend to combine with the lime, and thus greatly facilitate the escape of carbonic acid.

When fuel is abundant, or where labour is scarce, and the nature of the stone does not admit of its being broken up into small pieces, the largest blocks are placed in the centre of the kiln. Care must be taken not to overburn or *kill* the lime, as it is called, for if such be the case, it will not set or solidify. So also the lime must not be underburnt. The lime-burner will judge by certain appearances as to the time required, which varies with the nature of the stone and the fuel, the draught of the kiln, the state of the weather, and the direction of the wind. Before the burning is completed, the stones crack, the interstices diminish, the mass gradually sinks down ⅙th or ⅕th of its height, and the lime-burner ascertains whether the calcination is complete by driving a bar into the body of the charge. If it meet with considerable resistance, or strike against firm hard materials, the burning is evidently incomplete; but if it pass down easily, and meet with no more resistance than in passing through a mass of gravel, the burning is considered to be finished. Another test is, to draw a portion of the lime and slake it; but this is liable to error, for the lime will evidently vary in quality with its position in the kiln.

The behaviour of lime when *slaked* or *slacked* with water, is subject to much variation in different kinds of lime, and establishes certain important distinctions between them. Suppose, by way of experiment, the lime to be fresh, and to be immersed in a small basket in pure water for 5 or 6 seconds: the water is then allowed to run off, and the contents of the basket are turned into a stone or iron vessel. The observed phenomena may be as follows:—1. The lime hisses, crackles, swells, gives off much hot vapour, and immediately falls to powder. Or, 2. The lime remains apparently inactive for a variable time, not exceeding 5 or 6 minutes, after which the phenomena described under (1) become energetically developed. 3. The lime may appear to be inert for from 5 or 6 to 15 minutes: it then begins to smoke and decrepitate, but the heat and vapour are less than in (1), (2). 4. The above phenomena may not commence for an hour, or for a still longer time. The lime opens into cracks without any noise, and but little heat or steam is produced. 5. The phenomena are produced at very variable periods, and are scarcely perceptible. The heat is only evident to the touch: the lime does not readily fall into powder, and in some cases not at all.

Before the effervescent action has quite disappeared, the slacking of the lime should be completed. When the lime begins to crack and fall to pieces, water is to be poured down the sides of the vessel, so as to flow to the bottom, and to be absorbed by the lime. It should now be frequently stirred, and sufficient water be added not to flood it, but to bring it into a thick paste. It should then be left to itself to cool, and this may occupy two, three, or more hours. The lime should then be beaten up again, and more water added if necessary, still keeping it in the form of a tolerably stiff paste. A vessel should then be well filled with this paste, and placed under water, the time of the immersion being noted.

By treating limes in this manner, and carefully observing the results, they have been divided into five classes; viz. 1, the *rich* limes; 2, the *poor* limes; 3, *hydraulic* limes of *moderate* power; 4, *hydraulic* limes properly so called; 5, very *energetic hydraulic* limes.

1. The rich limes consist of pure, or nearly pure, oxide of calcium; and the purer the carbonate of lime from which they are produced, the more decided are the phenomena exhibited in slaking. They increase in volume to twice their original bulk, and even more: their consistency does not change, *i. e.* they do not set or solidify after years of immersion, and if exposed to pure water, frequently renewed, they would be entirely dissolved. 2. The poor limes, on being slaked, do not increase in bulk, or only to a trifling extent. They do not set under water, and they are dissolved by it, but a small insoluble residuum is left. 3. The hydraulic limes of medium power, set after 15 or 20 days' immersion, and continue to harden for months: in about a year their consistence is equal to that of hard soap. They dissolve with difficulty in water frequently renewed: they change in bulk on slaking similar to the poor limes. 4. The hydraulic limes set in 6 or 8 days after immersion, and continue

to harden for 6 months. In 12 months they are of the consistence of the softer building stones, and water has no longer any action on them. Their change in bulk is about that of the poor limes. 5. The energetic hydraulic limes set in 3 or 4 days after immersion: they are quite hard in a month, and are not acted on by running water: in 6 months they can be worked like the harder natural limestones, which they resemble in fracture. Their change in bulk is similar to that of the poor limes.

The differences in chemical composition, which produce these remarkable changes, will be noticed further on. But let us now consider the action of lime as a mortar or cement in its simplest form. If a rich lime be mixed up with water into a paste, and be left for some time exposed to the air, it gradually dries up, and there remains a friable mass of hydrate of lime. If, however, a thin layer of this paste be interposed between two smoothly dressed porous stones, the greater part of the water of the paste is absorbed by the stones, and the thin layer of hydrate of lime sets and adheres strongly to the stones. The absorption of the water must not be too rapid, or the hydrate will set too quickly, and in such case not become hard; hence the two dressed surfaces of the stone should be wetted before the lime is applied to them. The adhesion between the hydrate of lime and the stone is greater than the particles of the hydrate among themselves, hence the layer of hydrate should be very thin. A much firmer substance is, however, obtained by mixing with slaked lime two or three times its weight of quartzose sand, or any pounded stone, and well stirring up the whole with water. This mixture is spread by means of the trowel over the surface of the stone, and the other stone is placed upon it so as to press out the excess of mortar, and leave only a thin layer. In such case, each grain of sand is enveloped in a pellicle of lime which adheres to it strongly, and has the further advantage of preventing the mortar from contracting too much in setting, which contraction would cause the mortar to form numerous fissures, and to become friable. The setting of the mortar does not depend solely on the evaporation of the water, but also on the combination of the lime with the carbonic acid of the air. Those portions of the lime which are in contact with the air become converted into carbonate of lime; but the interior parts form a combination of carbonate and hydrate of great hardness. A great length of time is, however, necessary for the complete formation of this compound, for after the lapse of many years, the lime still exists as a hydrate in the thickness of the walls. General Treussart found in 1822, in demolishing one of the bastions in the citadel of Strasburg, erected by Vauban in 1666, that the lime was as soft as if it had been only just made. Dr. John also states, that in taking down a pillar, 9 feet in diameter, in the church of St. Peter at Berlin, which had been erected 80 years, the mortar was found to be perfectly soft in the interior. Hence it will be seen that this kind of mortar ought not to be placed in thick walls where it cannot possibly dry.

It is admitted, that quartzose sand, mingled with lime, exerts no chemical action; for if the solid mortar be dissolved in an acid, silica does not separate in a gelatinous state, which it would do if the sand were only partially in combination with the lime in the form of a silicate.

The quality of the mortar depends greatly on the mode in which it is prepared, on the quality of the sand, on the quantity of water with which the lime has been slaked, and also on the greater or less perfect mixture of the materials. A rough sand is preferable to a smooth grained sand, and in all cases it is desirable that the mortar set slowly. It is even stated that mortar assumes a greater solidity in autumn or winter than in the warm weather of summer, when evaporation is rapid. The sand usually preferred has a sharp grit, and the proportions in which it is used in different districts vary with the quality. The mortar for ordinary constructions consists of 1 part stone-lime and 3 of sand: the sand is made into the form of a basin, into which the lime is thrown in a quick state; water is then thrown upon it to slake it, and it is immediately covered up with sand: after remaining in this state until the whole of the lime is reduced to powder, it is worked up with the sand, and then passed through a wire screen, which separates the *core* or unslaked portion of the lime. That which has passed through the screen has more water added to it, and it is well worked up or *larryed* for use. In some cases the lime is placed in the middle of the heap of sand, and after water has been thrown out, it is well worked up with hoes: in a few hours it sets, and is fit for use. By this method lime takes up more sand than in the former: 72 bushels of good stone-lime, and 18 yards of sand, when formed into mortar, have a cubical content of 315 feet.

The mill for mixing mortar consists of a vertical spindle, to which a millstone is attached, and revolving on an iron bed, upon which the limestone or chalk-lime to be pounded is thrown. Curved pieces of iron, called *rakes*, are attached to the shaft, and by their revolutions keep the bed free. The lime being properly ground, is passed into another mill, where it is mixed with sand, and triturated by means of revolving rakes, attached to the arms of a horizontal wheel, moving round in a circular bed. Pug-mills, similar to those described under Brick, are also used.

Common mortar, made with rich lime, is not only used with hewn stone and brick, but also with rubble-work, small fragments of stones being placed in the large interstices to diminish the bulk of the mortar. Flint stones are also introduced so as to project, and thus prevent the mortar from being rubbed or worn.

In dry places, ordinary mortars made with rich lime are a considerable time in solidifying: in moist places they solidify with difficulty; and under water, as already stated, not at all; for, in the last case, the mortar becomes diffused through the water, and the lime is dissolved out. For constructions in moist places, or under water, hydraulic mortars are employed which solidify by virtue of a special chemical action, which we have now to consider.

The phenomena exhibited on slaking a pure or *rich* lime, have been already stated under (1). When, however, the limestone contains more considerable proportions of foreign matter, its properties become changed in a remarkable manner. If the limestone contain oxide of iron, manganese, or quartzose sand, it yields, by calcination, a lime which, when slaked with water, swells but little, and does not form a binding paste. This slaked lime hardens in the air in the course of time, but becomes disintegrated in the water. If, however, the foreign matter mixed with the carbonate of lime be clay, or even silica in a certain state of division, and in the proportion of at least from 10 to 15 per cent. of the weight of the carbonate, the lime produced by its calcination is still *poor*, but it possesses the property of solidifying under water in a longer or shorter time, provided it has not been too strongly calcined. This constitutes *hydraulic lime*, and its setting depends on a chemical combination between the lime and the silica of the clay.[1] A few experiments will show the mode in which the clay and the silica act in order to communicate this property to the lime. If milk of lime and clay, dried at a temperature of between 600° and 800°, be kept for some time in a stoppled bottle, the clay abstracts water from the lime, and the water no longer restores to reddened litmus paper its blue colour. If the clay be replaced by gelatinous silica, the latter also abstracts the water from the clay, but with less energy. The hydrate of alumina also takes up a little lime, but magnesia, oxide of iron, oxide of manganese, do not do so sensibly. This experiment shows that alumina, silica, and especially clay, have such an affinity for lime, as to take it up even from water, and to fix it in the form of an insoluble compound; whilst magnesia and oxide of iron do not possess this property; and silica, in the form of quartzose sand, is also inactive. If gelatinous silica, dried into a powder, be mixed with lime and stirred up with water, and then be left for some time to itself, a portion of the lime combines with the silica; for if the mixture be treated with an acid, a portion of the silica separates in a gelatinous state, proving that it was in combination with the lime.

If a very intimate mixture of carbonate of lime and clay be carefully heated, a substance is formed which hardens in the course of time under water. In this substance the lime exists for the most part in combination with silicate of alumina, for it is only partially soluble in water; and if the solution be made by means of a weak acid, there is a residue of gelatinous silica: hence clay on being heated in contact with carbonate of lime acquires the new property of being acted on by acids.

These experiments show that the solidification of the hydraulic limes under water arises from a combination of the hydrate of lime and the silicates of alumina and lime, a combination which determines a new state of aggregation of the mass, while it brings the lime into a state in which it is insoluble in water. A limestone containing silicate of alumina or silica in a state of minute division, brings the silica after calcination, or at the moment when the hydrate is formed by the addition of water, into contact with the lime at a multitude of points, so that the silica itself, now hydrated, acts the part of an acid, and unites with lime as a base, thus forming silicate of lime, which in its turn combines with the silicate of alumina and with a certain proportion of hydrate of lime thus rendered insoluble. Since silica has been regarded as an acid, the chemist has been able to explain a large number of phenomena, which embarrassed or misled earlier inquirers.

There are certain intimate mixtures of limestone and clay, called *argillaceous limestones*, which by calcination yield a hydraulic mortar without the admixture of any other substance: it sets under water with great rapidity, and becomes very hard in a short time. The term *cement* has been applied to this kind of mortar, and it appears to have been first introduced by Mr. Parker of London, who in 1796 took out a patent for the manufacture of what he called *Roman cement* from the nodules of septaria found in the London clay formation in the Island of Sheppy. The stones were broken into fragments, calcined at a high temperature approaching that of vitrification, and then reduced to powder by crushing and grinding. It was afterwards discovered by Mr. Frost that the septaria of Harwich produced a similar cement, and Mr. Atkinson found that the nodules of the argillaceous limestones of the secondary formations of Yorkshire could also be used for the manufacture of cements. In 1802 a similar material was found at Boulogne, and afterwards at Pouilly and Vassy in Burgundy and elsewhere. It is now found in the Isle of Wight, in the Bay of Weymouth, and may most probably be met with in all the marl beds which occur in limestone formations, and also in the tertiary

(1) Although hydraulic limes were known to the Romans, and cannot be said to have been lost sight of since the time of Vitruvius, yet no attempt was made to ascertain their composition and the reasons which enabled them to set under water until the time of Smeaton, in 1765. While engaged in the erection of the Eddystone Lighthouse, he wanted a cement that would harden at once under water, and accordingly he undertook a series of experiments for the purpose, and soon arrived at the conclusion, "that all the limes which could set under water were obtained from the calcination of such limestones as contained a large portion of clay in their composition;" and he further states, "that it remains a curious question, which I must leave to the learned naturalist and chemist, why an intermediate mixture of clay in the composition of limestone of any kind, either hard or soft, should render it capable of setting in water in a manner no pure lime I have yet seen, from any kind of stone whatever, has been capable of doing." The legacy which our illustrious engineer thus bequeathed to the "learned naturalist and chemist," notwithstanding some inquiries after it by Guyton de Morveau, Bergman, Saussure, and Colets Descotils, remained uninherited until the year 1813, when M. Vicat instituted a long and laborious inquiry, which terminated in placing the science of Mortars and Cements on a sure basis. The subject has received a good deal of attention from other chemists, especially the French, who have made it almost their own. The reader who desires to study it, will do well to consult the following works:—Treatise on Calcareous Mortars and Cements, artificial and natural, by L. J. Vicat. Translated by Captain J. T. Smith, 8vo. London, 1837. Nouvelles Etudes sur les Pouzzolanes Artificielles, par L. J. Vicat, 4to. Paris, 1846. Manuel du Chaufournier, in the Encyclopédie-Roret. 16mo. Paris, 1836. Dumas, Chimie appliquée aux Arts, liv. v. chap. viii. Regnault, Cours de Chimie, tom. ii. 1849. Payen, Chimie Industrielle, 1851; and Mr. Burnell's Treatise on Limes, Cements, Mortars, Concretes, &c., published in 1850, in Weale's Rudimentary Series.

clays in the form of detached nodules of a dark-coloured argillaceous limestone, traversed by veins filled with calcareous spar. When the nodules are obtained from the lias the colour may be blue; but in the tertiary formations brown or deep red, from the presence of oxide of iron.

It has been found by experiment, that a limestone does not possess hydraulic properties unless it contains at least 10 or 12 per cent. of clay. With this proportion, the lime produced from it by calcination on being slaked with water solidifies in moist places, or under water, in the space of about 20 days. The hydraulic properties are much more marked when the limestone contains from 20 to 25 per cent. of clay: the resulting lime on being mixed with water, sets in two or three days. A Roman cement, however, such as will set in a few hours, can only be produced from a limestone which contains from 25 to 35 per cent. of clay. The clay (silicate of alumina) should be in a state of minute division, and the silica be but loosely combined with the alumina: indeed, the clays best adapted to the purpose, give up a portion of their silica to a solution of caustic potash.

The following analyses of some of the most important argillaceous limestones adapted to the manufacture of hydraulic mortars and cements, will serve to guide the inquirer after these valuable substances in new localities.

1. *Argillaceous limestones of moderate hydraulic power.*

	From Mâcon.	From St. Germains. (Ain.)	From Bigna.
Carbonate of lime	89·2	85·8	83·0
——— magnesia	3·0	0·4	2·0
——— iron	0·0	6·2	0·0
Clay or Silica	7·8	7·6	15·0
	100·0	100·0	100·0

2. *Argillaceous limestones of great hydraulic power.*

	From Metz.	From Senouches.	From Lezoux. (Puy-de-Dôme.)
Carbonate of lime	77·3	80·0	72·5
——— magnesia	3·0	1·5	4·5
——— iron	3·0	0·0	0·0
——— manganese	1·5	0·0	0·0
Clay or Silica	15·2	18·5[1]	23·0
	100·0	100·0	100·0

3. *Cement Stones.*

	From Boulogne.	From London.	From Pouilly. (Côte d'Or.)	From Argenteuil, near Paris.
Carbonate of lime	63·6	65·7	57·2	63·0
——— magnesia	0·0	0·5	3·6	4·0
——— iron	6·0	6·0	6·6	0·0
——— manganese	0·0	1·9	0·0	0·0
Clay	23·8	24·6	25·2	27·0
Water	6·6	1·3	7·4	6·0
	100·0	100·0	100·0	100·0

When the limestone contains more than 30 per cent. of clay, it no longer yields a cement by calcining, and the paste formed with water is not sufficiently binding. The calcination of hydraulic limestones, and especially of cement stones, requires certain precautions. If the temperature be too high, the combination between the lime and the silicate of alumina becomes too intimate; there is an aggregation of the particles, and a new combination is not formed on the addition of water. The heat ought to be only just sufficient to deprive the limestone of the greater part of its carbonic acid, and the clay of its water. The cement stones are burnt in conical kilns with running fires, and in England with coke or coal. The stone loses about one-third of its weight by calcination, and the colour becomes modified according to the chemical constitution of the stone. The stone may be preserved for a long time without change in a dry room; but as it cannot be used in this form, it is ground at a mill, and packed in tight casks in order to preserve it from contact with the atmosphere until required for use; for if exposed, the powder absorbs moisture and carbonic acid, and would require a second calcination at a lower heat before it could be used. The sp. gr. of the stone is about 2·16; that of the calcined stone in block about 1·58; and that of the powder loosely packed about 0·85 to 1·00. The lightest and finest powder forms the best cement. The French engineers use a sieve for sifting the powder, in which 185 meshes go to the square of four inches of a side. Great care is required in mixing the powder: if too much or too little water be used, or if not applied as soon as made, it solidifies unequally, cracks, and adheres badly. The proportion of water should be about ⅓d of the cement in volume: it should be well beaten up, and if new and of good quality, it will set in five or six minutes, or under water in an hour at most. If sand be added, the setting is retarded. When mixed with sand in proportions varying from ½ to 1, 1½ and 2 to 1 of cement, the time of setting becomes 1 hr. 2 min. to 1 hr. 18 min. in the air, and much longer under water, and even 24 hours under sea-water. The pure cement is much stronger than when mixed with sand. The resistance to rupture offered by pure cement, after about 20 days' exposure, is about 54 lbs. per inch square: if sand be present in the proportion of ½ to 1 of cement, the resistance is 37 lbs.; and if in equal proportions, only 27 lbs. Thus it will be seen that, while pure lime increases in strength by the addition of sand, hydraulic lime, on the contrary, deteriorates. It will be seen from the analytical list, that finely-divided silica and clay are not the only substances that impart hydraulic properties to lime. A certain proportion of magnesia produces the same effect, although in a less degree. Thus it is found that certain magnesian limestones, dolomites for example, yield by calcination hydraulic limes of inferior quality; and their action is due to a chemical combination formed, when water is present, between hydrate of lime and hydrate of magnesia. It is even stated that a very intimate mixture of quicklime and carbonate of lime has feeble hydraulic properties; and limestone gently heated, so that a large portion of it remains in the form of carbonate, is slightly hydraulic. In the burning of rich limes, imperfectly burned fragments are always found, which have this character; and it appears to be due to the formation of a definite compound of carbonate of lime and hydrate of lime, CaO,CO_2+CaO,HO.

(1) Silica only, in a minutely divided state.

Hydraulic mortars are formed artificially by calcining intimate mixtures of rich lime and clay. Some extensive works of this kind were erected at Meudon, near Paris, under the superintendence of M. Vicat. The chalk, which is broken into lumps the size of the fist, is ground with clay, in the proportion of 4 parts chalk to 1 of clay, in a large vertical mill, with a plentiful supply of water: the liquid mixture is run off into a series of five troughs placed at different levels, and in them the matter held in suspension is deposited. A double set of troughs is required, for while one set is being filled, the matter is subsiding in the other. The subsidence is more rapid in shallow than in deep troughs. When the subsided matter is sufficiently firm to be handled, it is moulded into small prisms: these are placed upon a drying platform, and when of the consistence of freshly-quarried limestone, they are burned in a kiln.

A somewhat similar plan is adopted in England in the manufacture of what is termed *Portland*[1] *cement*, which is, in fact, an artificial hydraulic lime, composed of the clay of the valley of the Medway, mixed, in certain proportions, with the chalk of the same district. The materials are thoroughly ground up together with water, deposited, dried, and burnt; but in burning the heat is urged as far as the point of vitrification: the lime is in fact overburnt, and often irregularly so. Hence, much care is required in grinding up the different products of the calcination, to make them regular in their times of setting; for all overburnt limes, as well as natural cements, slack with difficulty in masses, and require to be broken up or ground to powder before being used. Portland cement also permanently expands in setting, so that it should not be used in positions where this property may interfere with the solidity of the work. It is of great value in external plastering.

The extraordinary tenacity of Portland cement was well illustrated by some experiments at the Great Exhibition, and noticed at length in the Jury Report, Class xxvii. In one of these experiments 2 six-inch cubes of Portland stone had about 4 months previously been cemented with about $\frac{1}{8}$th inch thick of Portland cement. The upper stone being held by iron clippers the weights were suspended from the lower one, the depth of the holes for the clippers being $\frac{3}{8}$ths inch. When the weight amounted to 3,780 lbs. the former broke. The square holes for the clippers being made deeper in another part of the stone, and the scale being once more loaded, the iron hook by which the scale was suspended broke at 4,580 lbs. the cement still remaining perfectly sound. In this experiment, therefore, the strength of the cement was not absolutely tested.

A block of neat Portland cement 16 inches long and 4 inches square, was suspended from each end, and the weight applied in the centre. It broke at 1,580 lbs. with a perpendicular, even, and good fracture. The block had been made 4 months. A similar block of neat Roman cement made from Harwich stone, and 7 weeks old, broke at 380 lbs.; but it is remarked that this must have been a bad sample.

Several beams were made of bricks joined together by Portland cement. A beam one month old made with 16 common stock bricks joined by very thick intervals of real Portland cement, on being held at the extremities, broke with a weight of 500 lbs. hung from the middle. The part broken was the brick only. A similar beam having one end only supported, and projecting 3 feet $2\frac{1}{2}$ inches from the bearing point, was weighed and broke with 256 lbs. exclusive of the scale, suspended from the free extremity. The fracture took place at the eleventh brick from the fixed end, and both brick and cement were fractured.

The resistance of Portland cement to crushing weights was also remarkable. A block of this substance 30 days old, measuring 18 inches $\times$ 9 $\times$ 9, was tested by a Bramah's hydrostatic press, and is said to have withstood a pressure of 41 tons for upwards of a minute, when it broke up with a report. A similar block of 1 part cement and 1 sand, 28 days old, crushed at 108 tons; 4 sand and 1 cement, 45 tons; 9 sand and 1 cement, $4\frac{1}{2}$ tons.

It is stated in this Report that upwards of two millions of bushels of Roman cement are made every year from the material obtained from the coast near Harwich, and that the price is from 30*s*. to 40*s*. per ton. What is called *Medina* cement is made from the Hampshire septaria. *Atkinson's*, or *Mulgrave* cement is made from the lias and some other rocks.

Hydraulic mortars are also prepared by mixing a rich lime with baked clay, or with certain volcanic substances to which the name of *puozzolano* has been applied, from Puozzoli, near Baia, not far from Vesuvius, from which the Romans obtained material for making mortar. A similar material has been found in the Vivarais, a theatre of extinct volcanic action in the centre of France; also near Edinburgh; at the village of Brohl, near Andernach, on the Rhine, where it is called *trass*, or *terrass*; and in other places where subterranean fire has been exerted. It varies greatly in appearance: it is found in powder, in coarse grains, in the form of pumice, scoria, tufa, or small rubblestone; and it may be brown, yellow, grey, or black, all these colours sometimes occurring in the same locality. The puozzolanos chiefly consist of silica and alumina, combined with a little lime, and mixed with potash, soda, magnesia, and oxide of iron, the latter capable of affecting the magnetic needle. According to Berthier, the trass of Andernach and the puozzolano of Civita Vecchia consist of—

	Trass.	Puozzolano
Silica	0 570	0·445
Alumina	0·120	0·150
Lime	0·026	0·088
Magnesia	0·010	0·047
Oxide of iron	0·050	0·120
Potash	0·070	0·014
Soda	0·010	0·040
Water	0·096	0·092
	0·952	0·996

(1) So called from its approaching in colour to Portland stone, not from being made of the stone, or in any way connected with the Isle of Portland

Basaltic and trap rocks behave in the same manner as the puozzolanos; but the difficulty of reducing them to powder precludes their adoption as ingredients in hydraulic mortars. But it is found that most burnt clays, if not too highly calcined, answer the same purpose, and that good artificial puozzolanos may be formed by reducing to powder common bricks, tiles, and pottery-ware.

The chemical reaction which takes place, by which a mixture of rich lime and puozzolano acquires hydraulic properties, is illustrated by the following experiment:—A common brick left for some time in lime-water, becomes covered with a pellicle of caustic lime, which is insoluble in water. If puozzolano in fine powder be left for some days in a bottle of lime-water well stoppled, it takes up the whole of the lime, and the water no longer exerts any alkaline reaction. Hence puozzolano has a strong affinity for hydrate of lime, and hydraulic mortar made with powdered puozzolano and lime, sets under water, and becomes insoluble in consequence of the affinity existing between hydrate of lime and puozzolano. That the compound thus formed is extremely hard, is evident from the Roman remains, which still exist for our instruction. The mortar is in many cases more solid than the brick, for while this has receded by wearing away, the mortar projects beyond it.

Concrete and *béton* belong to the class of mortars now under consideration. They are formed by mixing gravel or broken stone with lime, which may or may not have been previously worked up into a mortar. Concrete is valuable for the backing of coursed masonry, where walls are required to be of great thickness, and also in foundations and underground works, where it is confined on all sides, and not subjected to much cross strain; but it ought not to be used aboveground as a substitute for masonry. The lime should first be made into a hydrate or mortar before mixing with the pebbles. For water works required to set rapidly, a mixture of hydraulic limes, puozzolanos and sand may be used. The following proportions are recommended by Treussart:—

30 parts strong hydraulic lime, measured in bulk before being slacked.
30 parts trass of Andernach.
30 parts sand.
20 parts gravel.
40 parts broken stone, a hard limestone.

These materials diminished one-fifth after being worked up. The mortar was made first, and the stones and gravel added. This concrete must be used as soon as mixed. When the puozzolano of Italy is used, the proportions are:—

33 parts strong hydraulic lime measured before slacking.
45 parts of puozzolano.
22 parts of sand.
60 parts of broken stone and gravel.

This concrete to be exposed 12 hours before it is used.

A good concrete for sea or river works, is made by a mixture of a mortar made of 3 parts of fine sand to 1 of hydraulic lime unslacked, with equal quantities of gravel or broken stone, but the latter may be increased in the proportion of $1\frac{1}{2}$ to 1 of the mortar. No water should be mixed with the mortar and gravel during the mixing, and clay and other earths should be carefully excluded. This concrete should be spread in layers from 10 inches to 1 foot in thickness, and well rammed.

The stones used in concrete should be angular rather than rounded, so as to form more easily a solid mass. The usual material is unscreened gravel, which contains a good deal of sand, and large and small pebbles. Small irregular fragments of stone, granite chippings, are of great use in bonding the mass together. The proportion of lime and sand must depend on the quality of the lime, purer limes requiring a large proportion of sand, while the stone limes, a smaller quantity. This kind of concrete undergoes a slight permanent expansion before setting, which makes it valuable for underpinning foundations, and similar purposes; but it should not be exposed to water, or the lime will be washed out, and the concrete left in the state of loose gravel. In this way some writers distinguish concrete from béton, the former not standing water, and the latter being eminently hydraulic. According to this view, concrete is made with lime, and béton with hydraulic lime. Béton "differs from ordinary concrete, inasmuch as the lime must be slacked before mixing with the other ingredients, and it is usual to make the lime and sand into mortar before adding the stones. Concrete also is used hot, while béton is allowed to stand before being used, in order to insure the perfect slacking of every particle of lime."[1] Béton is chiefly used in submarine works as a substitute for masonry in situations where the bottom cannot be laid dry. It is lowered into the water in a box, with a bottom so constructed, that it can be opened by pulling a cord when the béton is discharged, in the exact spot, without having to fall through the water, which might wash away the lime.

Cements made from sulphate of lime or plaster of Paris are very numerous.[2] This substance forms the basis of *Keene's*, *Martin's*, *Parian*, and other cements. The plaster, in fine powder, is mixed with a saturated solution of alum, sulphate of potash, or borax, then dried in the air, and afterwards baked at a dull red heat. It is again reduced to powder, and sifted, when it is fit for use. It is slaked with a solution of alum, instead of pure water. This forms *Keene's* cement. When borax is used, it is called *Parian*. *Martin's* is made with pearlash as well as alum, and is baked at a higher heat than the others. *Stucco* is a combination of plaster of Paris with a solution of gelatine or strong glue. The mixture dries more slowly than when made with water, but is more durable. *Scagliola* is prepared from the finest gypsum: the sifted plaster powder is mixed with alum, isinglass and colouring matter into a paste, which is beaten on a prepared

(1) Treatise on Foundations and Concrete Works, by E. Dobson, C.E., published in Weale's Rudimentary Series.

(2) The ornamental varieties of sulphate of lime, such as alabaster, together with the methods of preparing and using plaster of Paris, are described under GYPSUM. See also LIME.

surface, with fragments of marble, &c. The surface prepared for it has a rough coating of lime and hair. The colours are laid on and mixed by hand somewhat after the manner of fresco. [See FRESCO-PAINTING.] Success depends on the skill of the operator in imitating the style, beauty, and veining of the marble to be imitated. When the cement has been properly laid on and hardened, the surface is rubbed with pumice-stone, and cleaned with a wet sponge. It is then polished by rubbing first with tripoli and charcoal, then with felt dipped in tripoli and oil, and lastly with oil alone. This leaves a durable polish equal to that of marble. Indeed, the material is as hard as marble, cold to the touch, and very durable. It is, in fact, an artificial stone, and properly belongs to our article on that subject. [See STONE.]

A *metallic sponge cement* for pavements was exhibited by M. Chenot. It is prepared by reducing certain ores of iron (oxides) into a spongy state by the removal of oxygen gas, in which condition they form a durable cement.

MOSAIC, a laborious mode of forming patterns or devices with minute pieces of differently-coloured substances strongly cemented together. This was the *Opus Musivum* of the Romans, of which many interesting specimens remain in the costly tesselated pavements of that people. Wherever their empire extended, traces of this art are from time to time discovered, and some of these are of the most elaborate description. At a little village near Seville, an extraordinary specimen was dug up in 1799, forming a pavement 40 feet long and 30 feet broad, and representing in the centre the circus games, with a variety of figures, horses, chariots, &c., surrounded by a fanciful border, with circular compartments containing figures of the Muses. This is supposed to have belonged to the hall of the baths of a palace constructed prior to the reign of Domitian, A. D. 81. Another beautiful mosaic pavement was discovered at Lyons in 1806, while numerous examples occur in different parts of our own country.

The materials for mosaic-work are marble, stone, plaster, enamel, wood, &c., but they may also be glass or precious stones. The walls of buildings as well as the floors were thus decorated from a very early period; and at length, at the commencement of the 17th century, by the use of exceedingly minute pieces, pictures were successfully copied, the various shades and colours being imitated in thousands of pieces of enamel. The artists of Rome are deservedly celebrated for mosaic pictures. A portrait of Pope Paul the Fifth, executed in this manner, is said to consist of one million seven hundred thousand pieces, each no larger than a grain of millet. The Roman mosaic does not consist of stones like that of Florence, but of an enamel artificially prepared, being a kind of glass coloured with metallic oxides: of these colours, there are said to be from 40,000 to 50,000 shades.

This enamel is so fusible that it can be easily drawn out into threads, small rods, or oblong sticks, of varying degrees of fineness, and somewhat resembling compositor's type. These rods are arranged in cases or drawers, properly labelled, so as to be ready to the artist's hand when required. In order to commence a mosaic picture, a piece of copper, marble, or slate, of the necessary size, is taken and hollowed out to the depth of about 3½ inches, leaving a border all round which will be on a level with the future picture. The excavated surface is intersected by transverse grooves, the better to retain the cement which is to be placed therein. The hollow is first filled with plaster-of-Paris, well smoothed, on which the proposed design is accurately traced in outline, and the latter strengthened by means of pen and ink. The mosaic work is commenced by scooping out with a tool a small portion of the plaster, putting a portion of mastic or cement in its place, and then inserting the pieces of glass or enamel according to the pattern. This cement, or mastic, is of a very strong and durable kind, which ultimately becomes as hard as flint: it is this which makes it necessary to fill the excavated bed of the stone by degrees, as the work proceeds, and not to put a larger quantity than can be employed while soft. Meanwhile the tracing on the plaster-of-Paris is interfered with as little as possible. Sometimes, on the portion of mastic inserted, a part of the picture about to be executed is delineated in the same way as in fresco painting, after which the fragments of enamel, selected according to their colour and gradation of tint, are driven in by means of a small wooden mallet. If the effect does not please the artist, he can easily withdraw certain fragments and substitute others while the cement is still fresh. By observing proper precautions an artist may keep the enamel moist for upwards of a fortnight. When the whole work is completed, any crevices which may exist are stopped with pounded marble, or with enamel mixed with wax, and the surface is ground down to a perfect plane and polished with putty and oil. The grinding and polishing are laborious works; indeed, the whole process of forming a picture in mosaic requires great patience, as well as skill, in the operator, for if the work be large, it may take several years in the execution.

The works in mosaic at the Great Exhibition well maintained the high reputation of Roman artists. A mosaic table, representing many of the cities of Italy, was exhibited by the inventor and artist, the Cavaliere Barberi, and was a specimen of rare taste and wonderful execution.

A series of beautiful mosaics by the Cavaliere Luigi Moja, representing a wild boar-hunt, a view of the Great Piazza of St. Peter's at Rome, the Colosseum, Pantheon, &c., were also of high merit, as was likewise a Roman mosaic representing the Temples of Pæstum at sunset, by Antonio Rocchigiani. Some remarkably fine specimens were also sent from the Royal Manufactory at St. Peter's, Rome, of a larger description of mosaic, intended to be viewed from a distance, the colours and drawing of which were perfect. A beautiful example of Florentine mosaic, being a table inlaid with various stones, was sent from the Imperial Polishing Manufactory near St. Peters

burg, and helped to grace the Russian department of the Exhibition. Florentine mosaic is essentially inlaid-work in gems, or pseudo-gems, such as agate, jasper, chalcedony, cornelian, &c. A slab of marble about $\frac{1}{8}$th of an inch thick, and generally black, is prepared, by carefully cutting out with the saw and file the patterns to be inlaid. The gems are then cut and accurately fitted to these patterns in their polished and finished state, for this kind of mosaic cannot, like the Roman mosaic, be ground and polished as a whole, because the substances used are of unequal hardness, and some of the stones would be worn away too rapidly. The greatest nicety is required in placing the stones, so that one shall not be in the least degree lower than another; a mistake of this kind is sufficient to ruin the whole. After the surface is thus prepared, it is veneered on a thicker slab, and is then fit for use. The Russian table just alluded to, was inlaid with jaspers and other stones from Siberia: it was of excellent workmanship, the produce of a manufactory where the workmen were all originally Italians, but where the art is now successfully practised by Russians. Some specimens of perhaps greater merit were sent from Tuscany, the stones consisting of pebbles from the Arno.

A third kind of mosaic has been introduced in England and elsewhere with good effect, and is now becoming known as Derbyshire mosaic. It is formed by replacing the jasper and agate of Florentine mosaic with marbles of various kinds, shells, cement, and glass. The latter substances have, in general, been too profusely used—giving brilliancy indeed, but not according with the principles of good taste. There were many interesting examples of this kind of mosaic in the Great Exhibition, chiefly table-tops beautifully inlaid. From Derbyshire, Mr. Vallance exhibited a table on which was wrought a most complicated and admirably finished wreath of flowers. Several other Derbyshire manufacturers also sent beautiful specimens. From Devonshire some very fine specimens, especially a table by Mr. Woodley of Torquay, illustrated the beauty of the marbles in that county, and the advancing skill of the manufacturers. The following remarks on Derbyshire mosaic are from the Jury Report, p. 568:—

"To a very limited extent, and by a very rude method, the art of inlaying in marble was practised in Derbyshire many years ago; but within the last quarter of a century it has made great and rapid advance, and about ten years since, the introduction of Florentine patterns, imitated in various coloured marbles, has exerted a very important influence on the trade. The first manufacture of mosaic in Derbyshire consisted of coloured spars and marbles of irregular shapes, imbedded in cement, and afterwards rubbed down and polished; these were called 'scrap tables,' and were succeeded by slabs, in which the spar and the marble were cut into definite forms arranged in patterns; but these also were rudely finished, as the workmen were not skilled in the art of making accurate joints, and the forms selected were simple and geometrical Up to this time the process was little more than veneering, and the results were rather imitative of brecciated marbles than intended to produce pictorial effect. The present Duke of Devonshire, by permitting his fine collection of Florentine work to serve as a guide and model to the Derbyshire manufacturers, and even lending them the inlaid butterflies, leaves, sprigs of jasmine, &c., for which the Florentine mosaics are celebrated, induced an imitation of a higher kind. The true art of inlaying was thus brought into successful operation, and materials foreign to the vicinity, as malachites from Russia, continental marbles, aventurine, and other glasses from Venice, with some cements, have been introduced. The use of these substances greatly diminishes the cost of the work. The condition of the trade at present may be judged of from the articles in the Exhibition, which show much taste and skill, though but little originality. The manufacture is carried on at Matlock, Ashford, Bakewell, Buxton, Castleton, and Derby, and the number of persons employed as mosaic workers exceeds 50. There appears to be a fair demand, and the prices, although sometimes high in London, are by no means extravagant at the place of manufacture."

By some writers the works in malachite, for which the Russian department of the Exhibition was so remarkable, are called Russian mosaic; but it appears to us inappropriate to apply this term to works in one material, whereas its usual application implies a variety of colours and materials skilfully brought together to produce harmonious effects.

MOSAIC GOLD, or AURUM MUSIVUM. See TIN. A recipe for making this substance is given under BRONZING.

MOTHER-OF-PEARL, or NACRE, is the hard, silvery, internal layer of several kinds of shells, especially oysters, the large varieties of which in the Indian seas secrete this coat of sufficient thickness to render the shell an object of manufacture. The genus of shell-fish, *Pentadinæ*, furnishes the finest pearls as well as mother-of-pearl: it is found round the coasts of Ceylon, near Ormus in the Persian Gulf, at Cape Comorin, and in some of the Australian seas. The dealers in pearl-shells consider the Chinese from Manilla to be the best: they are fine, large, and very brilliant, with yellow edges. Fine large shells of a dead white are supplied by Singapore. Common varieties come from Bombay and Valparaiso, from the latter place with jet black edges. South Sea pearl-shells are common, with white edges. The beautiful dark green pearl-shells called *ear-shells* or *sea-ears* are more concave than the others, and have small holes round the margin: they are the coverings of the *Haliotis*, which occurs in the Californian, South African, and East Indian seas.

In the Indian collection of the Great Exhibition, specimens of the finest pearl-shells were shown, such as the *Meleagrina margaritifera*, *Haliotis gigas*, *Haliotis iris*, and a large species of *Turbo*, which shells are known in commerce as *flat-shells*, *ear-shells*, *green snail-shells*, *buffalo-shells*, *Bombay shells*. Messrs. Fauntleroy and Mr. Banks had also some fine collec-

tions. The latter gentleman states that the shores of the Sooloo Islands afford the finest shells.

The beautiful tints of mother-of-pearl depend upon its structure; the surface being covered with a multitude of minute grooves, which decompose the reflected light. Sir David Brewster, who was the first to explain these chromatic effects, discovered, on examining the surface of mother-of-pearl with a microscope, "a grooved structure, like the delicate texture of the skin at the top of an infant's finger, or like the section of the annual growths of wood as seen upon a dressed plank of fir. These may sometimes be seen by the naked eye; but they are often so minute that 3,000 of them are contained in an inch." It is remarkable that these iridescent hues can be communicated to other surfaces as a seal imparts its impress to wax. The colours may be best seen by taking an impression of the mother-of-pearl in black wax; but "a solution of gum arabic or of isinglass, when allowed to indurate upon a surface of mother-of-pearl, takes a most perfect impression from it, and exhibits all the communicable colours in the finest manner, when seen either by reflection or transmission. By placing the isinglass between two finely-polished surfaces of good specimens of mother-of-pearl, we obtain a film of artificial mother-of-pearl, which, when seen by single lights, such as that of a candle, or by an aperture in the window, will shine with the brightest hues." [1]

It is in consequence of this lamellar structure that pearl-shells admit of being split into laminæ for the handles of knives, for counters, and for inlaying. Splitting, however, is liable to spoil the shell, and is therefore avoided as much as possible. The different parts of the shell are selected as nearly as possible to suit the required purposes, and the excess of thickness is got rid of at the grindstone. In preparing the rough pearl-shell, the square and angular pieces are cut out with the ordinary brass-back saw, and the circular pieces, such as those for buttons, with the annular or crown-saw, fixed upon a lathe-mandrel. The pieces are next ground flat upon a wet grindstone, the edge of which is turned with a number of grooves, the ridges of which are less liable to be clogged than the entire surface, and hence grind more quickly. If the stone be wetted with soap and water it is less liable to be clogged. The pieces are finished on the flat side of the stone, and are then ready for inlaying, engraving, polishing, &c. Cylindrical pieces are cut out of the thick part of the shell, near the hinge, and are rounded on the grindstone preparatory to being turned in the lathe. The finishing and polishing are described in the third volume of Mr. Holtzapffel's excellent work on "Mechanical Manipulation." Counters, silk-winders, &c., are smoothed with Trent sand or pumice-stone and water on a buff-wheel or hand-polisher, and are finished with rotten stone moistened with sulphuric acid, which develops finely the striated structure of the shell. For inlaid works the surface is made flat by filing and scraping; then pumice-stone is used, and after this putty-powder, both on buff-sticks with water; and the final polish is given with rotten stone and sulphuric acid, unless tortoise-shell or some other substance liable to be injuriously affected by the acid be present in the inlay In turned works fine emery-paper, rotten-stone and acid or oil are used. The pearl handles for razors are slightly riveted together in pairs, then *scraped, sand-buffed* on the wheel with Trent sand and water; thirdly, *gloss-buffed* on the wheel with rotten stone and oil, or sometimes with dry chalk rubbed on the same wheel; and fourthly, they are *handed up*, or polished with dry rotten-stone and the naked hand.

(1) Brewster's Optics, chap. xiv., one of the volumes of the Cabinet Cyclopædia.

MOTHER-WATER, the liquor left after a saline solution has been evaporated so as to deposit crystals on cooling.

MUCIC ACID. See Gum.

MUCILAGE. See Gum.

MUFFLE. See Assaying.

MULE. See Cotton—Introductory Essay, p. cxlvi.

MUNDIC. See Mine—Mining, p. 272.

MURIATIC ACID. See Hydrochloric Acid.

MUSK, the unctuous secretion of a glandular pouch or sac, situated in the skin of the abdomen of the musk-deer (*Moschus moschiferus*), an inhabitant of the great mountain range which belts the north of India and branches out into Siberia, Thibet and China. It is also found in the Altaic range near Lake Baikal, and in some other mountain ranges, but always on the borders of the line of perpetual snow. It is from the male only that musk is produced, and the secretion when dry is of a dark brown or black colour, and somewhat granular. Its taste is bitter, and its peculiar and penetrating odour is well known. It was formerly held in high repute as a medicine, and it is still so among eastern nations. The musk-deer is eagerly hunted for the sake of its costly perfume, which, however, is always much adulterated. Tavernier says that the odour of musk, when recent, is so powerful as to cause the blood to gush from the nose, and in this way he would account for the supposed adulteration of the article with dried blood. Chardin also says, "It is commonly believed that when the musk-sac is cut from the animal, so powerful is the odour it exhales, that the hunter is obliged to have his mouth and nose stopped with folds of linen, and that often in spite of this precaution the pungency of the odour in such as to produce so violent an hæmorrhage as to end in death. I have heard the same thing talked of by some Armenians who had been to Boutan, and I think it is true The odour is so powerful in the East Indies that I could never support it; and when I trafficked for musk, I always kept in the open air, with a handkerchief over my face, and at a distance from those who handled the sacs, referring them to my broker: and hence I knew by experience that this musk is very apt to give headaches, and is altogether insupportable when quite recent. I may add that no drug is so easily adulterated or more apt to be so." Tavernier states that at Patana he once bought 1,673 musk-bags weighing 2,557½ ounces, containing 452 ounces of pure musk.

The musk from Boutan, Tonquin, and Thibet is most esteemed; but it is probable that its strength and the quantity produced by a single animal varies with the season of the year and the age of the animal. A single musk-bag usually contains from 2 to 3 drachms. When cut off it is tied up and is ready for sale. Musk is imported into England from China in caddies of 60 to 100 oz. each: that from Bengal is inferior, and from Russia of a still lower quality. The best is that contained in the natural follicle or pod. When adulterated with the animal's blood it forms into lumps or clots. It is sometimes mixed with a dark, highly coloured, friable earth; the musk is then of a more friable texture, harder and denser than genuine musk. Previous to 1832 the duty was 5*s*. an oz.: in 1842 the duty of 6*d*. an oz. produced 53*l*., showing that 2,120 oz. had been entered for consumption. In 1846 it was declared free of duty.

Musk is very remarkable for the diffusiveness and subtlety of its scent; everything in its vicinity soon becomes affected by it, and long retains it: a very minute portion, such as a grain or two, will scent a room for years, and is sufficient for imparting to articles of dress, &c., a powerful perfume. One part of musk will communicate its odour to 3,000 parts of inodorous powder. Boiling water dissolves 90 parts of genuine, Tonquin musk; alcohol only 50 parts. Musk is soluble in ether, acetic acid, and yolk of egg. Moisture seems to favour the odour of musk, for when dry it yields but little scent, and this becomes powerful when moistened. An artificial musk is prepared with nitric acid and oil of amber.

Musk does not appear to have received an adequate chemical examination.

MUSKET. See Gun.

MUSLIN. See Weaving.

MUSQUASH. See Fur—Hat.

MUSTARD. A plant (*Sinapis*) of which there are several species, some of which appear to be indigenous to Great Britain. It was formerly cultivated in Durham, but is now chiefly raised about York. Previous to the year 1720 it was prepared for use by pounding the seeds in a mortar and roughly separating the integuments; but it occurred to a woman named Clements, who resided at Durham, to grind the seed in a mill and then to dress the powder as corn flour is dressed. The mustard prepared in this way was very superior in quality and appearance, and being patronised by George I. it sold largely: the woman kept her process secret for a time and realized a large fortune. This is the origin of the term *Durham mustard*. The mustard which is cultivated for its seeds is the *Sinapis nigra*. *S. alba* often grows wild among corn, and is also cultivated with the garden cress for eating in the seed leaf as a salad. It germinates even more readily than cress; the seeds strewed on wet flannel or on cork floating on water soon put out tender leaves; so that a salad may be produced in a few days by the side of the fire in winter.

Mustard is cultivated in the East for the sake of the fixed oil which is obtained from its seeds by expression. By means of the cake left after this process, an essential oil ($C_8H_5NS_2$) is obtained by distillation with water. The oil does not exist in the seed, but is developed in the presence of water in consequence of a species of fermentation. The cake is at first inodorous, but on sprinkling it with water it soon begins to ferment, and to exhale the penetrating odour of mustard. On distilling the cake with water a yellow oil denser than water passes over with the aqueous vapour: the oil is purified by a second and a third distillation. It then becomes colourless, has a pungent odour and a burning taste: it immediately blisters the skin; its sp. gr. is 1·015; its refractive power 1·516; it is very soluble in alcohol and ether; it boils at 290°; the density of its vapour is 3·44. It dissolves sulphur and phosphorus with the aid of heat. The chemical relations of this oil are of interest to the scientific chemist.

MYROBALAMS.—See Leather.

MYRRH, a gum-resin (containing from 60 to 70 per cent. of gum, and 30 to 40 of resin) obtained from the bark of the *Balsamodendron myrrha*. Although known as an object of trade from the earliest times (for it is mentioned in Gen. xxxvii. 25), the tree does not appear to have been known until 1825, when Ehrenberg brought a specimen of it from Gison on the borders of Arabia Felix. Myrrh is imported from the East Indies in large agglomerated tears of a reddish brown or brownish yellow colour, semi-transparent, and of a dull fracture: they have a peculiar balsamic, pungent odour, and a bitter, aromatic, somewhat pungent taste. It is usually mixed with fragments of other gums and resins. It also contains 2 or 3 per cent. of volatile oil.

NACRE, the French word for Mother-of Pearl. See Shells.

NAILS. The forging of nails formerly gave employment to many hands in the neighbourhood of Birmingham. Hutton, the historian of that town, states that when approaching it from Walsall, in 1741, he was "surprised at the prodigious number of blacksmiths' shops upon the road, and could not conceive how a country, though populous, could support so many people of the same occupation." In some of these shops he observed females wielding the hammer; and on inquiring "whether the ladies in this country shod horses," he was answered, with a smile, "They are nailers." Before the introduction of machine-made nails, it was estimated, that in the neighbourhood of Birmingham alone upwards of 60,000 persons, men, women, and children, were occupied in nail-making; and that many of the iron-works in the same district furnished every week from 100 to 200 tons of *split iron rods* for the manufacture. These nails are termed *wrought*, to distinguish them from those *cast* in moulds, or *cut* or punched out of plates of iron by machinery. Wrought nails are also made from plates rolled for the purpose, and then slit by means of slitting rollers into *nail rods* or *split rods*, of various sizes and qualities, according to the variety of nail required. For *horseshoe nails* the best refined iron is required, to allow of their being drawn out

fine, without breaking in the hoof. A very tough metal is also required for *wheelwrights' nails*, to allow of their being forcibly driven against the iron tire: *hurdle nails* must be of good fibrous iron, to allow their points to be clenched, and their broad heads to stand the hammer. The various *sorts* of forged nails are very numerous, probably over 300, with at least 10 different sizes for each sort, so that there are upwards of 3,000 nails with different names, all of which are perfectly understood by the persons who manufacture them or use them. The retail terms, *fourpenny, sixpenny, tenpenny*, &c., are not only indefinite in themselves, but vary in different localities. A much more precise method is to assign to the sorts certain specific names which mostly express the uses to which they are applied; as *hurdle, pail, deck, scupper, mop*, &c., while other sorts, of more general application, are named after the form of their heads or points, as *rose, clasp, diamond*, &c. heads, and *flat, sharp, spear*, &c. points. The thickness is expressed by the terms *fine, bastard, strong*. The length of some sorts is expressed in direct lineal measure, but it is more usually included in the weight of 1,000 of the nails referred to. Thus the term *7 lb. rose* means a nail with a rose head and a sharp point, the length being about $1\frac{1}{2}$ inch, and 1,000 nails weighing about 7 lb. Rose nails are made from $1\frac{1}{2}$ to 40lbs. per thousand.

The following are some of the principal forms of nails without reference to their size:[1]—

1. The kind called *rose sharp* are extensively used for coopering, fencing, and various coarse purposes in which hard wood is used. A thinner sort, called *fine rose*, are used in pine and other soft woods, their broad spreading heads being calculated to hold the work down. 2. The *rose*, with *flat* or *chisel* points, is used where the wood is in danger of being split by the driving in of sharp points, which act as wedges; while those with flat points, being driven with their edges across the grain, prevent the splitting and hold faster. 3. *Clasp* nails are commonly used by house-carpenters in deal and similar woods: their heads,

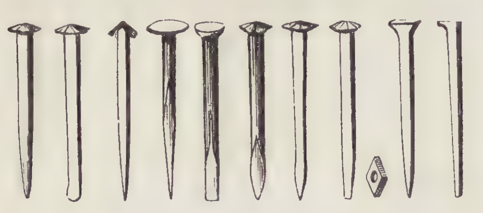


Fig. 1489. VARIETIES OF NAILS.

projecting downwards, stick into the wood and clasp it together, and when driven below the surface, allow a plane to pass over them. 4. *Clout* nails are used for nailing iron work and various substances to wood: they have a flat circular head, round shanks, and sharp points. The *counterclout* (5) have countersinks under their heads, and chisel points, and are much used by wheelwrights and smiths. 6. *Fine dog* is distinguished from a thicker nail, called *strong* or *weighty dog*. They are also used for nailing down stout iron work, and for various other purposes where the heads (which are very solid, and slightly countersunk) are not required to lie flush with the work; their shanks are round drawn, and their points speared, which adapts them for piercing and clenching well. 7. The *Kent-hurdle* has a broad, thinnish rose-head, a clean drawn flat shank, and a good spear-point, well adapted for nailing and clenching the oaken bars of hurdles together. *Gate nails* are similar in form. 8. *Rose-clench* is a sort much used in ship and boat-building. They are used in nailing on the wood sheathing, which is soft, and liable to split unless bored; and as the nails have no points, the ends being left square, they punch out their own holes, driving a portion of the wood before them, hold very fast, and render boring unnecessary. Hence they are much used in making packing-cases and boxes. The term *clench* is derived from the mode of employing them in boat-building, in which they are clenched either by hammering down the extremity, or by placing over it a little diamond-shaped plate of metal, called a *rove*, and rivetting the end of the clench nail down upon it, whereby the planks, &c. are firmly drawn together. 9. *Horse-nails*, in common use. Formerly the heads were made square, but the preference is now given to the countersunk, chiefly on account of their lying flush in the groove made for them, and more securely attaching the shoe to the hoof. 10. *Brads* form a large class of very useful nails. *Tacks* are also a very numerous and useful class of nails. The chief place of manufacture for them and other very small kinds is Bromsgrove in Worcestershire, where it is a common feat of the work-people to forge a thousand (1,200) tacks so small as to fill the barrel of an ordinary goose-quill, their weight being only about 20 grains.

The apparatus required by the nailer is very simple: it consists of a small hearth or forge for heating the nail rods; an anvil, a hammer, and a few swage tools.

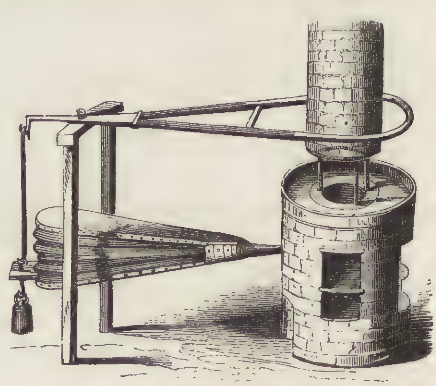


Fig. 1490. NAIL FORGE.

One of the best forms of nail forge is that by Mr Sperme, of Belper, and represented in Fig. 1490. It

(1) We are indebted for these specimens and their uses to an excellent article on Nails, in Hebert's "Engineer's and Mechanic's Cyclopædia."

is circular in form, so that 5 or 6 persons can work at it at the same time. The brickwork from the base is carried up in a cylindrical form to the height of 24 inches, with proper openings for the ashes, water-troughs, and the nozzle of the bellows. The circular aperture in the centre is then covered with a fine cast-iron grating, which forms the bottom of the furnace. The courses of brickwork are next carried up a foot higher, and the whole is surmounted by a cast-iron plate, with a rim, or border, so as to form a convenient dish for holding fuel to replenish the fire. In the centre of the cast-iron top plate is an opening corresponding with the fire-place, to which is fitted an iron ring, supporting on 3 iron pillars another ring which carries the brickwork of the chimney. The bellows are suspended from a frame, and are worked by a lever or *rock-staff*, which encircles the chimney, so that one of the 5 or 6 persons who work at the same fire is continually blowing it, and the fire being thus kept at the proper heat for welding, good and sound nails are produced.

The anvil used in forging nails is a small cube of steel, fixed to a heavy iron block surrounded with stones, and imbedded in smithy slack, so that the small anvil only is seen. The size of the hammer depends on that of the nails to be forged, and resembles the file-cutter's hammer in shape, [see FILE], the face being sloped or inclined considerably towards the handle. The degree of obliquity, the weight of the hammer head, and the size and shape of the handle, are matters of individual experience, one nailer seldom being able to work comfortably with another man's hammer; so that in moving from place to place each man carries with him his own hammer.

The nailer begins his work by putting into the fire the ends of 3 or 4 nail-rods, and works the bellows until they are at the proper heat. He then takes one of the rods, and resting it on the anvil, draws out the nail by means of a few skilful blows. The end, thus forged, is now cut off by means of a chisel, or *hack-iron,* a short distance from the cutting edge of which is a stop or check for determining the length of the nail. With nails of moderate size the rod may retain sufficient heat to allow a second nail to be forged and cut off; but if the nails are of large size the rod must be returned to the fire after one nail is cut off. While the rod is heating the nailer forms the heads of those cut off by means of a *bore,* or piece of strong iron, 10 or 12 inches long, with a steel knob at each end perforated to the size of the shank or collar of the nail, and countersunk so as to correspond with the head. Taking up the nail, still red-hot, with a pair of plyers, and putting it into the bore, point downwards, the nailer strikes it upon the projecting end, which moulds it to the shape of the perforation. By using different bores the various forms of heads are produced. The process is conducted with great quickness and dexterity. Instances are recorded of remarkable feats by nailers, and we have heard of one man making 170,000 double-flooring nails, 1,200 to 1,000 of 20lbs. weight for 2 successive weeks.

Nails are formed by *casting* as well as forging; they are brittle, but their cheapness recommends them for such coarse purposes as the lathing of plasterers, garden walls, stout shoes and boots, &c. Their brittleness may be partially removed by annealing, and a superior kind may be manufactured from malleable cast iron. [See ANNEALING.]

Nails are also extensively manufactured by *cutting* or *punching*. Mr. Holtzapffel states (Mechanical Manipulation, Vol. II.) that the first patent for making nails that he has met with was granted to John Clifford, 17th July, 1790. The patentee employed "two rollers of iron faced with steel, in which were sunk impressions of the nails, half in each roller. The indentations were arranged circumferentially with the heads and tails in contact, so as to extend the grooves around the roller, and roll the whole rod of iron into a string of nails, which required to be separated from each other with shears, nippers, or other usual means. Sometimes many grooves were cut around the rollers, and a sheet of iron was then converted into several strings of nails that required to be separated nearly as before." The same inventor, also, took out a patent soon after for making nails by punching. "The plates of metal were forged or rolled taper to the angle of the nails, and were then cut up by a punch and bed, each made taper, and also to the angle of the nail. Nails that required heads were afterwards put into a heading tool, or bed, having a taper hole of corresponding form, that left a small piece of the thick end projecting; and the head was upset with a punch or die." After this period some 30 or 40 patents were taken out for making brads and nails; and in machinery of this kind the natives of the United States of America are distinguished as inventors, in consequence of the large demand for nails in the construction of block-houses. So long since as the year 1810, the Americans had a machine which performed the cutting and heading at one operation, and produced above 100 nails per minute.

The principle upon which nails are cut may be illustrated by a narrow strip of paper, by cutting from the end with a pair of scissors, triangular sections in the form of fine wedges, and turning the paper over after every cut, so that the head, or broader part of every clipping, may be taken from the point of the preceding one, and *vice-versâ*. In this way we get the form of that kind of shoe-nail called a *sparrable*, or *sparrow-bill*, from its resemblance to the mandible of the bird. In Fig. 1491, the larger wedges, A, represent sparrables, and the smaller ones B, *sprigs*,

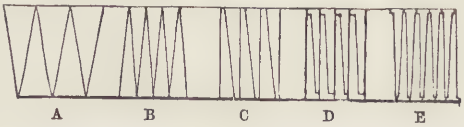


Fig. 1491.

which are also used by shoemakers and other workmen. If, instead of this slip of paper, we have a slip or rand of iron, and instead of scissors the fly-press, with its cutting punches, [see BUTTON], it is easy to see how nails of the simple form described are manufactured. By using the punch the nails are not bent

or curled, which they are liable to be if cut with shears. In Fig. 1492, *m* is a rectangular mortise in the bed of a fly-press, used for cutting brads, such as are shown at C, Fig. 1491; the punch, *p*, is made to fill the bed, but a portion of the punch represented by the black part of the figure, is nicked in, or filed back to the size and angle of the brad. A pin or stop *s*, guides the strip of metal *i* into the mortise, and in order to prevent it from passing too far over the hole in the bed, the punch is never raised quite out of its bed: the metal is thus stopped by the tail of the punch, and its outer or rectangular edge removes the brad. The strip is turned over after every descent of the punch, so that the head of one brad is cut from the point of the one previously made, and this turning over is quickly and accurately done with the assistance of the stop and the tail acting as guides. The upper surface of the bed is a little inclined, in order that the cutting may begin at the point of the brad. In cutting brads with heads and headed nails, as at D, E, Fig. 1491, the whole of the strip of metal can be used without waste by the arrangement shown in Fig. 1493, simply by turning over the strip after each cut. *m m* represents, as before, the rectangular opening in the bed of the press, *p* the tail of the punch fitting into it: *s* is a stop placed at a distance from the opening in the bed corresponding to the vertical height of the head, so that the strip of iron overhangs the aperture by that quantity: it will also be seen that the width of the point of the brad is equal to the projection of the head. Now when the strip of iron is first applied, a wedged-shaped piece is cut off, equal to the difference between the tail of the punch and the bed, and there is a small projection left in the strip near *s*. On turning over the strip, this projection rests against the tail of the punch, as shown at *s*, so that the next cut removes a perfectly formed brad, and leaves the head of another ready formed on the strip.

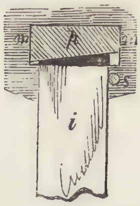


Fig. 1492.

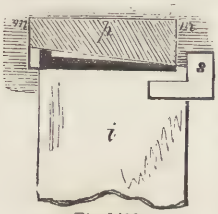


Fig. 1493.

The iron from which nails are to be cut or punched is rolled to the proper thickness, and the plates are cut up into strips of the width required for the length of the nails by means of a powerful cutting-press. When brads or nails are cut out by steam power, which is the usual course, a fly-press is not used, but the moving cutter is attached to the end of a long arm, (as in the lever-press, Fig. 1494,) to which a rapid up-and-down motion is given by a crank or an eccentric, as at *e*. The strip of metal is held in a spring clamp *c*, at one end of an iron rod, the other end of which is supported by a forked rest *r*; and by this simple contrivance the boy who attends the machine can turn the metal over with great rapidity while the moving cutter is ascending. In order to prevent the necessity for turning over after every cut, a *toggle* or *knee-joint* is substituted for the screw of the fly-press. In this joint "the two parts *a b* and *b c*, Fig. 1495, are jointed together at *b*; the end *a* is jointed to the upper part of the press, and *c* to the top of the follower. When the parts *a b* and *b c* are inclined at a small angle, the extremities *a* and *c* are brought closer together, and raise the follower; but when the two levers are straightened, *a* and *c* separate with a minute degree of motion, but almost irresistible power, especially towards the completion of the stroke. The bending and straightening of the toggle-joint is effected by the revolution of a small crank united to the point *b* by a connecting rod *b f*." (*Holtzapffel.*) The whole press is moved upon the pivots *e e* by the rod *g*, so that it is alternately inclined to the right and left to the angle of such nails as are wedge-shaped or have no heads. Some machines are so contrived that as soon as the nail is cut off, it is grasped between forceps or dies, and a hammer, also set in motion by the machine, strikes a blow which upsets or spreads out the metal, forming the flat head in cut nails and tacks.

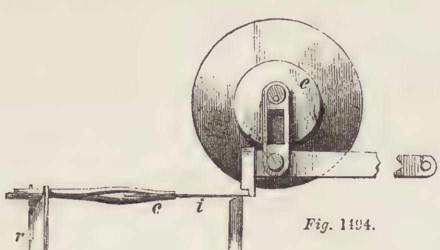


Fig. 1494.

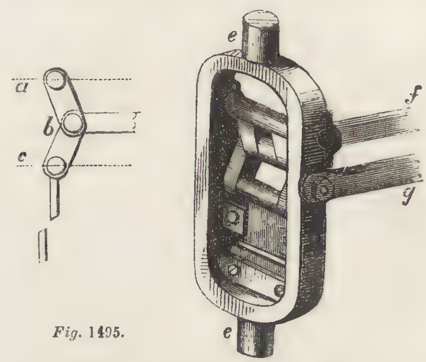


Fig. 1495.

After the nails are cut or punched, they are annealed by being put into close iron boxes, heated in ovens, and then left to cool slowly. They are then packed in strong hempen bags, or made up in bundles or casks, according to the market for which they are destined. Of the vast quantities of nails manufactured in Great Britain, by far the larger proportions are consumed at home: there is, however, a considerable trade to the colonies and the East. The continent of Europe is chiefly supplied with nails from Holland and Belgium. The Jury Report of the Great Exhibition states that "the price of nail-rods is lower in Belgium than in England; a fact which seems to indicate that a constant and regular demand for one

description of iron will not only insure its supply, but diminish its cost, possibly by the inducement held out to the exercise of ingenuity on the means of economising the cost of production." Some of the hand-made nails of Belgium are referred to in the highest terms of commendation; and those of Austria are mentioned as being remarkable for a peculiar twist given to the shank of the nail, which greatly increases the hold. This twist is not unusual in railway spikes. It is said that the United States of America manufacture from 35,000 to 40,000 tons of nails every year. "For this and other purposes, such as ship-building, boiler-making, &c., large quantities of cheap iron are imported from Great Britain, which, owing to the wide extent of American sea-board, can be supplied to most of the southern states of the Union at a cheaper rate than would be the case even were the prices in Pennsylvania and Great Britain the same at the works."

NANKEEN. See COTTON, Vol. I. p. 446.

NAPHTHA. In our article ASPHALTUM a number of natural inflammable substances are enumerated, among which is *naphtha*, *rock oil*, or *petroleum*. The term naphtha is usually limited to the thinner and purer varieties of rock oil; and petroleum to the darker and more viscid liquids. They are mixtures of various hydrocarbons; but in its purest form naphtha may be said to consist of C_6H_5, and yielding a vapour of the density of 2·8. Such a hydrocarbon is obtained as a natural product at Baku on the shores of the Caspian, where the soil is a clayey marl impregnated with naphtha. It is also procured from Monte Ciaro, near Piacenza in Italy, by sinking pits in the horizontal beds of argillite, which gradually fill with water; and the naphtha oozes out of the rock and floats upon the surface, from which it is skimmed off. Naphtha may also be obtained by the distillation of petroleum, and it is one of the results of the destructive distillation of coal [see GAS-LIGHTING]: it often passes with the gas to the distant parts of the apparatus, and may be found in gas-meters and gas-meter tanks, and even in the mains.

Carefully rectified naphtha, whether from natural or artificial sources, appears to possess similar properties. The sp. gr. of the purest Persian and Italian naphtha is said to vary from 0·750 to 0·760, while that of coal-naphtha may be ·820 or higher. The odour of the natural naphtha is bituminous but not unpleasant; that of coal is penetrating and disagreeable. It does not congeal at zero. It ignites readily, and burns with a voluminous sooty flame. It is not soluble in water, although it communicates its odour to that fluid. It dissolves in absolute alcohol, in ether and the oils. The boiling-point varies in different specimens from 320° to 365°. It dissolves caoutchouc, and hence its value in the manufacture of water-proof clothing. [See CAOUTCHOUC.]

NAPHTHALINE, $C_{10}H_4$, a white, solid, crystalline matter obtained by distillation from coal-tar. It fuses at 176° into a clear colourless liquid, which crystallizes on cooling. It boils at 413°, and gives off a vapour of the density of 4·528. Its sp. gr. is about 1·05: it is unctuous to the touch; its taste is slightly aromatic. It exhales a faint peculiar odour, which has been compared to that of the flower of the narcissus: it slowly evaporates if left exposed. When ignited it throws off a large quantity of smoke, or rather of black snow. It is slightly soluble in hot water, but abundantly so in alcohol, ether, the oils, and naphtha It is deposited from its hot alcoholic solution in iridescent crystals.

NAPIER'S BONES. See CALCULATING MACHINES, Fig. 397.

NAPLES YELLOW. This fine colour, used in oil-painting and for porcelain and enamel, is prepared in Italy by a secret process. Dr. Ure gives the following recipe: 12 parts of metallic antimony are to be calcined in a reverberatory furnace with 8 parts of red lead and 4 parts of oxide of zinc: the mixed oxides are to be fused, and the mass then triturated and elutriated into a fine powder. Many of the purposes for which Naples yellow was formerly applied, are now supplied by chromate of lead.

NATRON. See SODA.

NAVAL ARCHITECTURE. See SHIP.

NAVIGATION INLAND. The prosperity of a country depends greatly upon the facility with which its different parts and members can communicate with each other; and it is instructive to observe how rapidly England developed her commerce and industry as soon as she began to construct extensive means for locomotion. Next to good roads, the introduction of a system of inland navigation must be regarded as one of the most notable epochs in the history of British commerce; and although railroads have in some measure superseded canals, yet at their first introduction they were comparatively as important as railroads now are. The most remarkable thing is, that while many other nations had long enjoyed the advantage of canals, England did not even begin to adopt the system until the year 1758, when the Duke of Bridgewater set the example. At this time on our best roads the force of traction was not less than $\frac{1}{8}$th or $\frac{1}{10}$th of the load or carriage; and when this was heavy the speed could not exceed 2 miles or $2\frac{1}{2}$ miles per hour; whereas on a canal the force of traction at that pace is not above $\frac{1}{1000}$th, or at the most $\frac{1}{900}$th, of the load. This advantage was soon appreciated, and a few years after the genius of Brindley and the perseverance of the Duke of Bridgewater had been crowned with success, Great Britain was penetrated with canals in every direction, so as to connect her various points of product and consumption. Before the general introduction of railroads, the aggregate length of navigable canals in England alone exceeded 2,200 miles; and in addition to canals, such rivers as were capable of it were rendered navigable; so that there was no place in England south of Durham that was distant 15 miles from water communication, while the principal towns and seats of manufacture were in direct communication therewith. It is even stated that the general introduction of railroads, which it was supposed would entirely supersede canals has not only not done so, but has in some cases actu-

ally improved their traffic; for while a railway to a populous place increases its means of commerce and industry, and consequently requires a larger amount of carriage, the lower toll charged on the canal than the railway will cause the former to be preferred for certain heavy goods.

It has not been ascertained in what country artificial water communications were first constructed; but it is probable, that canals which had originally been made as aqueducts for drainage, or for irrigation, were afterwards applied to the purposes of navigation. Works of this kind were constructed in Egypt at a very early period, and they are know to have existed in China before the Christian era. The first canal constructed in Europe is supposed to be that cut by Xerxes across the low isthmus of Athos. The Romans formed canals in Italy, and in the Low Countries about the outlets of the Rhine. In modern Europe, the art of cutting canals was first practised in Northern Italy and Holland. Those formed in Lombardy, between the eleventh and thirteenth centuries, were chiefly intended for irrigation. [See DRAINAGE.] The canal from Milan to the Tesino was rendered navigable in 1271. In the 12th century, when Flanders was the commercial centre of Europe, canals were constructed. In Holland, canals are like the roads of any other country, and are used as such.

The chief principle to be worked out in the construction of a canal, is the formation of a perfect level or series of levels. In a flat country like Holland, the work is easy, but where the face of the land is diversified by hill and dale, the object may be attained by three methods. 1st. By elevating the depressed portions by means of embankments and aqueducts; 2dly. By depressing the elevated portions by means of cuttings and tunnels; and 3dly. By forming a series of stairs or steps termed *locks*, by which one level portion is made to communicate with another either higher or lower than itself, the water being maintained at the higher level by means of gates, so placed that the pressure of the water against them keeps them closed.[1] The proportions in which these three methods are combined, are determined by a careful survey of the intended line of canal; and the general level at which it is fixed must have reference to the means of obtaining sufficient feed of water from the adjacent country, and also to its junction with other canals.

It is, of course, desirable, as far as possible, so to proportion the excavations and embankments, that the quantity of earth from one shall suffice to form the other. A canal running along the side of a declivity, may require one bank to be raised more than the other, or one may require to be excavated, while the other is embanked. When embankments and excavations frequently alternate, the mass of earth required for raising one part is made to correspond as far as possible with that removed from the other. In order to avoid cuttings in solid rock, it may in some cases be desirable to carry the line of the canal out of the direct route. These and many other points, the engineer will have to determine in laying out the line.

The form of channel for the canal is of importance. Except in tunnels the sides are seldom vertical. The bottom is generally made to slope off upwards, the amount of slope being regulated by the nature of the soil. The slope may be liable to wear from the motion of the water in such a way as to make the towing-path irregular in width. This is remedied to a certain extent by planting the sides with aquatic shrubs, and also by driving stakes into the banks at short intervals along the water line, so as to form a kind of rough wicker-work. Where embankments are formed of loose materials, or excavations are made in earth, sand, or rock so porous as to allow the water to filter through, it is usual to make the excavation wider and deeper than the intended dimensions, and to line it to the thickness of $1\frac{1}{2}$ to 3 feet with *puddled* clay, that is, good clay well beaten up or *tempered* with water, and then mixed with a certain proportion of gravel, sand, or chalk. If clay were used alone, and the water in the canal sunk below the ordinary level, the exposed part of the clay would crack, and when the water rose again, it would escape by the cracks, and enlarge them, and at length wash away all the clay. The puddle-stuff is usually applied in 2 or 3 strata; the first stratum, about 10 or 12 inches thick, is first allowed to set, when another course of about 9 inches is applied, and so on until the required thickness is attained, care being taken to work the puddling-stuff each time, as as to unite it with the stratum just below. On the top course of puddle, a layer $1\frac{1}{2}$ to 2 feet thick of common soil is laid. A trench 3 or 4 feet in width is also formed in the middle of each side bank to at least 3 feet below the bottom of the canal, and this *puddle-ditch* or *gutter* as it is called, is filled up with puddling-stuff, its object being chiefly for the purpose of preventing rats and vermin from perforating the banks; for when once a small opening has been made for the water, it is quickly widened by the flow, so that in a few hours, damage may be done which may require weeks or months to repair, and the canal may even be emptied of its water. Fig. 1496 represents a section of a canal with a puddle lining P C, 1 foot 6 inches thick at the bottom, and 3 feet in the slope. T is the towing-path, 10 feet wide, and N S the natural surface. Fig. 1497

(1) The various claims to the merit of having invented the canal lock have led to the disturbance of much learned dust. It was probably first used in Italy, and was an improvement on the ancient sluice. Belidor, in his "Architecture Hydraulique," attributes the invention to the Dutch. Italian writers state that the celebrated Leonardo da Vinci first used locks, in the Milanese canals, in 1497; but these writers are by no means agreed on this subject. A recent writer is disposed to attribute to England an early, perhaps an independent, application of the pound lock, on the ground that the English term *lock* is purely national. It is not, he remarks, the Italian *sostegno* or *conca*, the Dutch *sluys*, the French *écluse*, but the Anglo-Saxon *loc*, or enclosure; and he infers that if we had borrowed the invention, we should also have borrowed the name. In reply to this argument, it has been said that our term is at least an exact translation of the Dutch *sluys* and the German *schleusse*, which, whether to be traced through the French *écluse* and Italian *chiusa* to the Latin *claudo* and *cludo*, or to the nearer source of the Teutonic *schliessen*, has the same signification, to *enclose*, or *shut up*.

shows a section where the soil is retentive; T is the towing-path, and P the puddle ditch.

In carrying a canal over a valley, an embankment may be formed, or an aqueduct constructed of timber, stone, brick, &c. In a deep and extensive valley, an aqueduct would be preferred. Where the Shrewsbury canal passes over the valley of the Tern for a distance of 180 feet, Telford constructed an aqueduct of cast-iron, the nuts and screws only being of wrought-iron. A canal aqueduct of unusual dimensions was constructed by Mr. Jessop, on the Ellesmere canal, for crossing the Dee, about 20 miles from

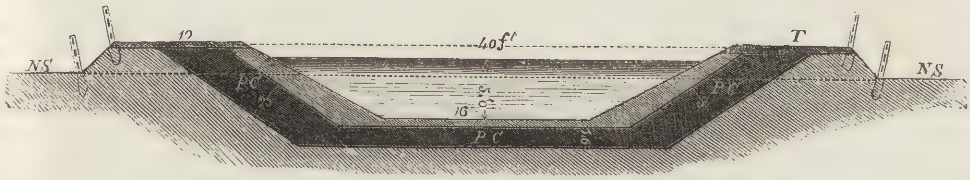


Fig. 1496. TRANSVERSE SECTION OF CANAL WITH PUDDLE LINING.
(*Birmingham and Liverpool Junction Canal. Telford.*)

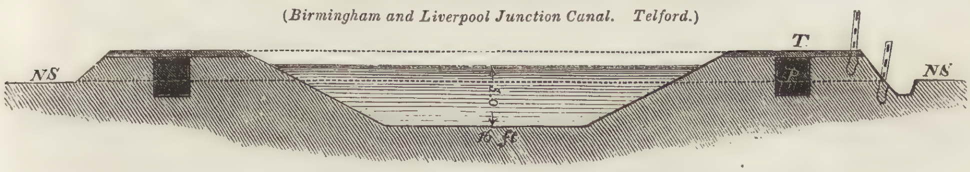
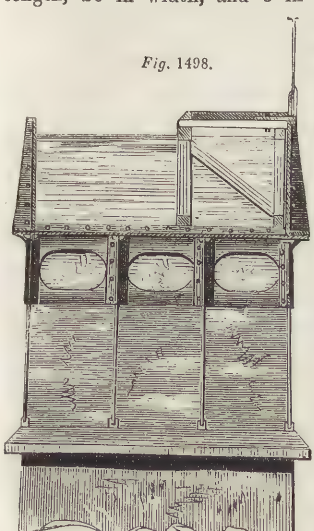


Fig. 1497. TRANSVERSE SECTION IN A RETENTIVE SOIL.
(*Birmingham and Liverpool Junction Canal. Telford.*)

Chester. 19 massive conical pillars of stone, 52 feet apart, the middle one being 126 feet in height, support a number of elliptical cast-iron ribs, which, by means of vertical and horizontal bars, support a cast-iron trough or aqueduct about 1,000 feet in length, 20 in width, and 6 in depth, composed of massive sheets of cast-iron cemented and riveted together, having on its south side an iron platform and railing for the towing-path, which overhangs the water, and is supported at intervals on timber pillars, as represented in Fig. 1498. Of embankments, one of the largest is between Wolverton and Cosgrove, on the Grand Junction Canal; it is half a mile in length, and in some parts 30 feet high, the object being to avoid the construction of a number of locks. In the valley of the Boyne, in Ireland, is an embankment 90 feet high.

Fig. 1498.



When the ground is higher than the level of the intended canal, the reverse process of excavation is adopted, unless the depth is so great that a tunnel is preferable. In some cases, the value of the ground above may cause a tunnel to be preferred to an excavation. The first tunnel driven for the purpose of canal navigation, was on the Languedoc canal, in France, and the first in this country, was the entrance made by Brindley to the Duke of Bridgewater's canal at Worsley. In the construction of a tunnel, the level and bearings of the line require much care.

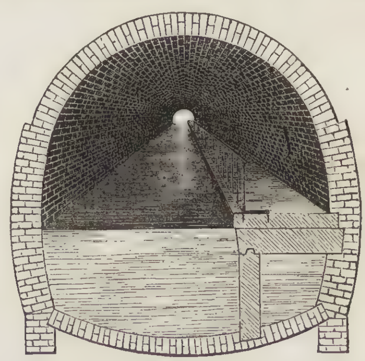


Fig. 1499. CROSS SECTION OF HARECASTLE TUNNEL
(*on the Trent and Mersey Canal, Telford*).

The ground is first surveyed by tracing a line in a vertical plane parallel to the direction of the tunnel, to obtain which the relative levels of the principal points along the line upon the surface are ascertained. At certain places along this line, vertical pits or shafts are sunk either for the purpose of ventilation, or for commencing and carrying on the work of driving the tunnel at several places simultaneously. The earth, or rock, is hoisted out through the shafts, and water is pumped out. The shafts having been sunk to the required

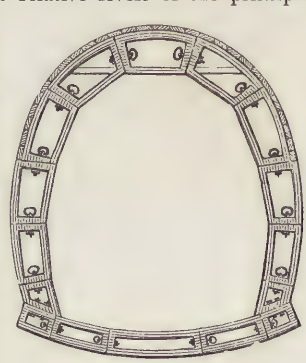
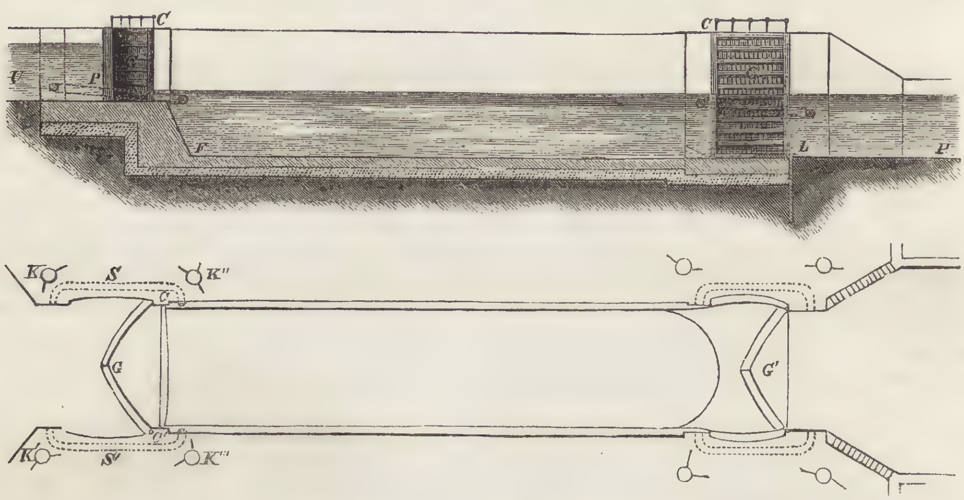


Fig. 1500. ELEVATION OF CENTERING.

depths, as ascertained from the levels taken at the surface, a heading or small tunnel sufficiently high and wide to allow the men to move freely while at work, is commenced just below the crown of the intended tunnel. It is carried forward from one working shaft to another as nearly as possible in a straight line, until a connexion is formed between all the shafts and the two ends of the tunnel. If in the progress of the heading the air become too impure for the men to respire, an air-shaft is commenced from above, and sunk to the point where the men ceased to drive. In driving the tunnel of the Thames and Medway canal, 11 air-shafts were required in addition to 12 working shafts. When the heading between two working shafts is completely excavated, the roof of the tunnel is begun, and this may require to be completely lined with brick or stone, or it may be sufficient merely to smooth the surface.

One of the distinguishing features of a canal is the means by which an ascent is made to a higher level, or a descent to a lower. This is done by means of *locks*. The level portions between locks are termed *pounds*, and the frequency with which locks and pounds alternate will depend on the undulations of the ground. If the ground ascend uninterruptedly, or ascend and descend at short intervals, the pounds must be short and the locks frequent; if the ground be tolerably level, but few locks will be



Figs. 1501, 1502. SECTIONAL ELEVATION AND PLAN OF A CANAL LOCK.

required. There is one English canal in which a lock occurs on the average at every half-mile; while in another case, there is only one lock in 19 miles.

A single lock usually consists of an oblong chamber about 70 or 80 feet long, C C′, Fig. 1501, and 7 or 8 feet wide, or only just sufficient to allow the boats to pass through it. Its sides and invert, or floor, are lined with brick or stone. By means of this chamber an upper pound is connected with a pound next below it, or a lower pound with the next upper one. In Fig. 1501, U P is a portion of the floor of the upper pound, and L P of the lower pound, which is on the same level as the floor of the lock-chamber. P G are the gates which retain the water at the upper level. They are slightly curved, as shown at G, Fig. 1502, and when in motion, they turn upon their ends C C′ as centres: they are of sufficient breadth to meet and form an angle at G, a position in which the gates mutually support each other, and the pressure of the water against them tends to keep them more closely shut. They are opened by means of capstans K K′, the chains being attached to the gates under the water, and passing through tunnels in the sides of the lock. They are closed by two other capstans K″ K‴, the gate C G being shut by K‴, and the gate G C′ by K″. A similar pair of gates is placed at the lower end of the lock C L: they are on the same level as the upper gates, and hence have a greater

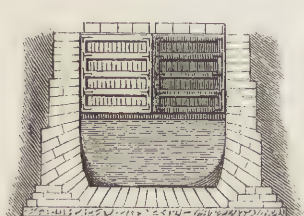


Fig. 1503. UPPER LOCK GATES.

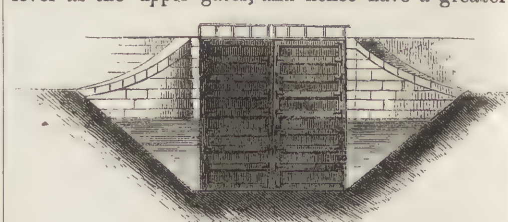


Fig. 1504. LOWER LOCK GATES.

length than those, as much as the upper pound is above the lower. This will be seen in Figs. 1503, 1504.

Now, suppose a laden barge has to pass from a lower to an upper level, an operation which is called *locking up*, it is thus performed:—On arriving at the lower gates L G′ these are thrown open, the boat admitted into the lock-chamber, and the gates are

closed behind it. Water from the upper pound is then let into the lock-chamber by opening the channels s s′, Fig. 1502, in the sides of the upper part of the lock, which can be opened or shut by means of sluices, and water then pours in from the higher

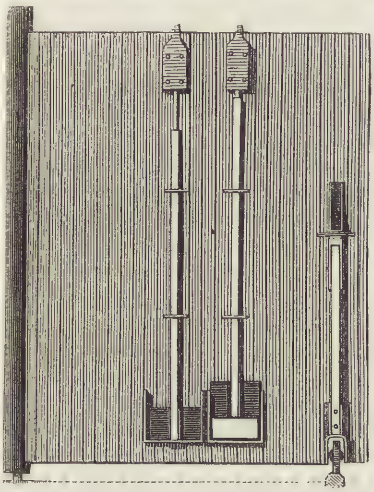


Fig. 1505. FRONT ELEVATION OF IRON LOCK GATE. (*Caledonian Canal.*)

pound, until the water in the lock-chamber is at the same height as in the higher pound. As the water in the chamber rises, the boat rises with it, and when the flow has ceased, the upper gates G are thrown open, the boat is towed out of the lock, and proceeds

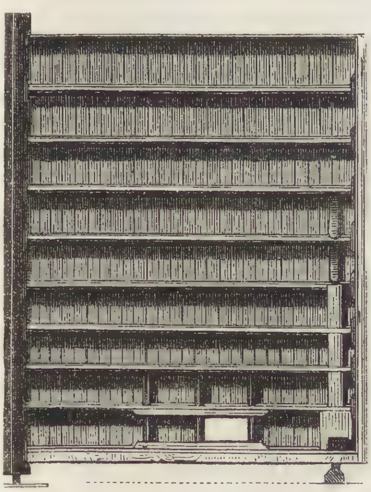


Fig. 1506. BACK ELEVATION.

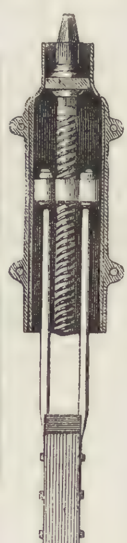


Fig. 1508. SCREW FOR OPENING AND SHUTTING SLUICES.

Fig. 1507. SECTION SHOWING THE CURVE OF THE GATE.

on its journey along the upper level. In passing from a higher to a lower level, or *locking down*, water is admitted into the lock from the higher level; the gates are then opened to admit the boat, and are immediately closed. The sluice is next opened in the opposite gates, not as in the former case, for the purpose of raising the water in the lock, but for letting it out until its surface coincides with that of the lower level. This being done, the gates are opened, and the boat towed out as before. Thus it will be seen that a lock is a kind of liquid stair by which the boat may ascend or descend, not by ceasing to float for a single instant, but by varying the level of the water in the enclosed space, or lock. In this arrangement a certain quantity of water is lost from the higher level, depending on the direction in which the boat moves, and whether the lock be full or empty at the time. The following will represent all the cases that may occur:—

	Finds the lock,	*Lets out of the upper pound,*	*Leaves the lock,*
Boat descending	Full	No water	Empty.
	Empty	1 lockfull	Empty.
Boat ascending	Full	1 lockfull	Full.
	Empty	1 lockfull	Full.

Hence, when a series of boats follow each other in the same direction, up or down, 1 lockfull of water will be expended for every boat that passes; but if the boats pass alternately up and down, only 1 lockfull will be required between each pair, since every ascending boat requires a lockfull and leaves the lock full, and every descending boat, finding the lock full, does not draw upon the upper pound for water.

When the slope is considerable within a short distance, a *chain* of locks, or succession of chambers, Fig. 1509, is constructed, the lower gates of one chamber forming the upper gates of the next below it. By this contrivance, only one more than half the

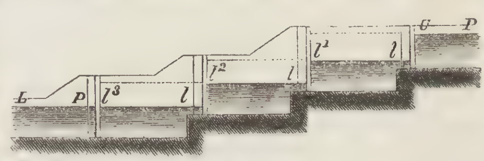


Fig. 1509.

number of gates for the whole of the series, supposing them to be detached, is required, and much of the machinery for opening and shutting them is saved. This arrangement, however, causes a large expenditure of water in certain cases, as, for example:—

	Finds the locks,	*Lets out of the upper chamber,*	*Leaves all the locks.*
Boat descending	Full	None	Empty.
	Empty	1 lockfull	Empty.
Boat ascending	Full	1 lockfull	Full.
	Empty	as many locksfull as there are contiguous chambers.	Full.

In these cases the term *empty* does not mean that the chambers contain no water, but that the water is in each at its lower level $l\,l^1$, $l\,l^2$, &c., the dotted lines showing the levels in the full locks. Hence it will be seen, that when a number of boats follow each other in the same direction, up or down, each boat will require one lockfull of water; but if a number of boats pass alternately up and down, each pair will require between them as many locksfull as there are contiguous lock-chambers, which in the present case

is three; for the previous boat having left all the chambers empty, the ascending boat will require 3 locksfull, but as it leaves all the chambers full, the next descending boat will not draw off any water from the upper chamber.

It may readily be imagined, that the summit level of a canal, from which all the lower pounds obtain their supply, may gradually become exhausted, especially in summer, or in dry seasons, when evaporation is rapid or water scarce. By a contrivance called a *double lock*, one half of the water which would otherwise escape to the lower level is saved. A double lock consists of two oblong chambers placed side by side, but separated by a massive brick partition in which is a sluice connecting the two chambers; each chamber has a gate at each end, the upper connected with the upper pound of the canal, and the lower gates with the lower pound. If we suppose one of these chambers to be filled to the level of the upper pound, and the other chamber to that of the lower pound, and that a boat is about to ascend, the arrangement would be as follows:—The boat would be towed into the chamber in which the level of the water was lower, and the gate would be closed behind it; all 4 gates being now closed, the sluice in the partition wall would be opened, water from the full chamber would flow into that containing the barge until there was an equality of level in both; the sluice would next be closed, and a valve opened for admitting water from the higher pound, by which the barge would be raised to the higher level, and the upper gate of the chamber in which the barge is, being opened, the barge would be towed out. In the reverse operation, or locking-down, a barge would be towed into the upper level chamber, the gates shut, the sluice opened, and the water in the two chambers brought to the same level; the sluice would then be closed, and a valve opened between the lower pound and the chamber in which the barge is floating, the water sinks to the lower level, the lower gate is opened, and the barge is towed forwards on her journey. It will thus be seen, that by means of a double lock a good deal of water is saved. If the lock contain more than two chambers, the economy may be still further carried out, but the increased cost would not compensate for the advantage. The average *lift* of a lock, or the difference of level between the upper and lower pounds, is about 8 feet, but it may vary from a few feet to 18. If in a canal of a certain length a certain amount of rise is to be effected, it may be produced by a small number of deep locks, or a larger number of shallow ones. In the former case less time is expended, and in the latter less water.

The supply of water to a canal is an important consideration. Where the two extremities of a canal, such as the Great Ship Canal of Holland, communicate with the sea, the supply of water is from the sea. This, however, is not a very usual case. Most of the canals in England are fed by natural springs, which must be so regulated as to discharge their waters into the canal to supply the waste of lockage. When a navigable communication has to be established between separate valleys, or basins, and a double lockage, or descent, in both directions, from an intermediate summit level, cannot be dispensed with, the summit may be too much elevated above the adjacent streams on either side to obtain a supply of water from them; or such streams may be engaged in turning mills, &c., and their waters cannot be spared for the canal. In such a case a supply of water is obtained by collecting the flood waters of the higher grounds into reservoirs, from which they may be drawn off as occasion requires for the service of the canal. In the construction of such reservoirs much will depend on local circumstances, but the engineer takes care to fix a reservoir at a level sufficiently low to collect the flood waters from a tolerably wide extent of country, while at the same time the reservoir is situated so as to discharge all its water into the summit of the canal. If the bottom and sides of the reservoir are, from the nature of the rock, impervious to water, the expense of rendering them so artificially will be saved. Where the reservoir is situated some distance from the canal, the water may be discharged from it into the canal by a brook-course, or ancient channel; but it is more usual to construct a *feeder*, or artificial brick channel, for the purpose; and in many cases, cast-iron pipes have been found most economical, as in crossing valleys or other streams. A clause is usually inserted in Canal Acts of Parliament, authorizing the company to search for, and divert to their use, all springs of water within certain limits on either side of their line as feeders for the canal. In the Acts for the Newcastle-under-Lyne Junction, the limit is fixed at 1,000 yards; in the Aberdeen, Polbrook, Thames and Medway, Wilts and Berks, and a few others, the limit is 2,000 yards. In very dry weather all the water sources of the company may be so exhausted that they cannot obtain a supply adequate to the waste by lockage and evaporation, and it then becomes necessary to purchase water from the neighbouring water companies. The cost of this is sometimes very high.

The lockage water is sometimes economized by means of *side-ponds*, which serve a purpose similar to that of double locks. Two ponds are used for each lock, each pond having the same horizontal area as the lock, and made to receive one-fourth of its fill of water. One of these ponds, that to the left of A B C, &c., Fig. 1510, has its bottom at half the height or lift of the lock (which is represented by the vertical height between the top and bottom horizontal dotted lines), so that when a valve *s* is opened into it from the full lock A, this pond receives one-fourth of its contents as shown at B: this valve is now shut, and another *s'* opened between the lock and the second pond, the bottom of which is at one-fourth the lift of the lock, and this pond in its turn receives another fourth of the water as shown at C: the second valve is next shut, and the remaining half-lockfull of water is allowed to flow into the lower pound in the usual manner, leaving the lock and ponds as shown at D. When the lock is to be filled again, the lower

pond is first opened and the water allowed to flow into the lock, as at E, and then the higher one is opened, by which half the rise is effected, as at F. Mr. Field has proposed to construct side ponds to act on the principle of an inverted siphon, the water rising to the same height in one limb as in the other. The lock is to be connected with a side pond by

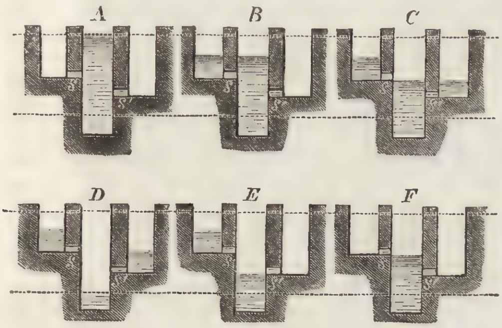


Fig. 1510.

means of a long pipe or culvert, so that when the water in the lock is allowed to flow suddenly into the empty pond, it may rise in this nearly to the level to which it falls in the lock, and as soon as this occurs the valve or sluice in the culvert is shut. A similar effect takes place when the water is to be restored to the empty lock, only whatever may have been the loss of water in the former case, the total loss is now doubled.

The boats or barges used on canals are specially constructed for the kind of traffic in which they are engaged. They are much longer and narrower than those used for river navigation, and are tracked with more ease and speed than when of a wider and shorter figure: they also do less damage to the sides of the canal. In the central districts of England the boats are usually sharp at both ends, and have no projecting stern; they are guarded by three rows of wrought-iron bands, which extend round the bows to the distance of 20 feet on each side above and below the water line; the bottom is nearly flat, and there is a keel which appears to be a useless appendage. Coarse and heavy goods are conveyed in open barges; but goods which require to be packed with care, and defended from the weather, are usually carried in *fly-boats.* These are long and very narrow barges with flat bottoms, in which the goods are stowed nearly from end to end, and to a considerable height above the edge of the boat, and the whole is protected by a canvass covering. There is a small cabin at the stern end for the boatman, who frequently has his family with him. The boats and barges are tracked or towed by one or two horses,[1] which move at the rate of from 3 to 4 miles an hour upon the gravelled towing path at the side, the horse being connected with the boat by means of a long rope. Some of the early tunnels were made so small as not to leave room for a towing path, in which case the horse is unloosed from the boat, and conducted by the road above to the other end of the tunnel. The boat is got through by two men, who place two boards in a horizontal position near the head of the boat, and lying down on their backs push against the walls of the tunnel with their feet in a slanting direction. In this way they urge the boat slowly forward until it emerges from the tunnel, when the horse is hooked on as before. In some cases a steam-tug is used for drawing the barges and boats through the tunnels.

About 20 years ago a remarkable increase in speed was made on the Glasgow and Paisley canal, in boats for the conveyance of passengers. These boats were run at the rate of 9 or 10 miles an hour; they are 70 feet in length and about 5½ broad: they carry 70 or 80 passengers, and occasionally over 100. The hulls of the boats are formed of light iron plate and ribs, and the covering is of wood and light oil-cloth, so arranged that all the passengers may be under cover. Each boat is drawn by 2 horses, the tow-line being formed into two branches at the front end, and the horses attached one behind the other. The first horse has blinders, and the boy rides on the hinder horse and guides both. The horses are changed every 4 miles, after a run of from 20 to 25 minutes, and they make 3 or 4 stages per day. When two boats pass, the horses of one boat stop just before they come up to the horses of the other boat, and a boatman takes the tow line off the hook and holds it to prevent it from coming in contact with the other boat, which passes it at full speed. The fares are a penny a mile in the first cabin, and three-farthings in the second. This plan has now been in operation for many years on the Birmingham canal; the horses go at a gallop, and this speed is not found to injure the banks of the canal. There have been several proposals to propel the boats by means of steam; but the weight of steam machinery would require the moving power to be greatly increased, and canals as they now exist are not adapted for increased velocity. With swifter boats there ought to be no interruptions from locks or from the contractions offered by tunnels and bridges, and slow and heavy craft would also interfere. Mr. John Lake has recently taken out a patent for combining a railway and steam power with the advantages furnished by the water-way. Trains of boats are to be passed from one level to another by means of inclined planes. An account of this invention, illustrated by numerous diagrams, is given in the *Mechanics' Magazine,* Nos. 1508, 1509. It resembles the method adopted on some of the American canals for simplifying if not superseding the system of locks. For example, on the Morris canal there are 22 inclined planes. Each plane is a kind of railway with an inclination of 1 in 21, the rails being of iron, and extending for some distance into the lower pound, and at their upper extremity terminating in a kind of lock-chamber. On this railway is a timber carriage, supported by a truck at either end, sufficiently large to carry one of the canal boats with its cargo of 30 tons. In raising a boat the carriage is run down upon the

(1) In Holland the *trekschuiten*, or drag-boats, are sometimes tracked by men: the same practice is common in China, and was the case on the Thames and the Severn till near the end of the last century.

railway into the lower pound, and passed under the boat, which being secured by chains, the whole is drawn up the incline by machinery into the lock at its upper extremity, the lower gates of which are then closed, and the water being admitted from the upper pound, the boat is floated off the carriage, and pursues its journey on the canal. A boat is lowered by a converse arrangement. A similar contrivance to the above was introduced by Mr. William Reynolds on the Shropshire canal many years ago. One of these inclines is 600 yards in length, with a perpendicular rise of 126 feet: another incline rises 207 feet in a length of 350 yards.[1]

Some remarkable contrivances have been made of late years for superseding locks, among which we must refer to the mechanical *lift* invented by Mr. James Green, and applied by him on the Grand Western Canal. In this arrangement two cradles are suspended from the extremities of a chain which passes over the rim of a large wheel moving on a horizontal axis. The two cradles are nearly filled with water, and counterpoise each other.

In passing a boat from a higher to a lower pound, one cradle is raised to the higher level; the gate of the cradle and the end gate of the upper canal are then removed; the boat is floated into the cradle; the doors or gates are then lowered into the grooves in which they fit, so as to close securely the ends of the channel and the cradle. The cradle and boat are then let down to the lower pound, into which the boat is admitted by lifting the gates out of their grooves. While the loaded cradle is being lowered, the other cradle, containing water only, rises: the two cradles, however, still continue to counterbalance each other, since the boat occupies a considerable space in the cradle, which had previously been filled with water, but which, as the boat passed into it, escaped into the upper canal, and the weight of water thus displaced is equal to that of the boat itself; so that, although the cradle has received the additional weight of the boat, it has lost the same weight of water, and consequently the two cradles balance each other. But, in order to allow the boat to descend, water is gradually allowed to escape from the cradle containing water only. The raising of a boat from a lower to an upper level is of course equally simple. The advantages of this contrivance over locks are, a saving in the first cost of construction, and in the time and quantity of water required. Mr. Law states[2] that a boat can be raised or lowered through 46 feet, the height of a lift, in three minutes; whereas, on the usual system, five or six locks would be required to attain the same lift, the time in passing through which would be about half an hour. As to the water expended (without taking into account that lost by leakage and in working the lift), a quantity equal to the weight of the boat passes up or down the lift in a contrary direction to that of the boat; so that if the traffic in opposite directions be equal, the upper level will lose no water.

A very complete and apparently efficient canal lift has recently been invented by Mr. Archibald Slate, of the firm of Cochrane & Company, Woodside Iron Works, near Dudley. The conditions required in this *equilibrium lift*, as it is very properly called, are, that the boats float in water during transfer; that gates or sluices in the main line of the canal be entirely dispensed with; and thirdly, that the boat be transferred from one level to the other, without loss of water, or the use of more power than is necessary to overcome the friction of the machinery.

The lower level of the canal is divided into two branches, or arms, L P, L P, Figs. 1511, 1513, which are carried along each side of the upper level U P, to a sufficient length to receive an ordinary canal boat. The depth of each branch is sufficient to allow a boat C B, with a full load, to float over the ends of an iron caisson or tank A, filled with water, and sufficiently large to float a loaded boat. Over these branches is a timber or iron framework, upon the top of which, at points immediately over the upper and lower branches, are fixed rails R R, on which are placed carriages K K, containing a series of wheels, over which run the chains employed for lifting the caissons. At the bottom of the branches, on the upper and lower level, are placed the caissons A, which are carried by straps attached to crossbearers, and suspended by the chains immediately under the framework. On one side of the framework is suspended the large shaft S S, carrying the four drums D D, on which the suspending chains wind and unwind in the operation of raising and lowering the caissons; the two sets of chains being wound on the respective drums in opposite directions, so that when one caisson is raised, the other is at the same time lowered. On each end of this shaft S, is a bearing or journal, which is grasped by an eye or strap, in which it can revolve; to these straps are attached the ends of the equilibrium connecting chains L L, the other ends of which are fixed to the cams C C′. These cams are keyed fast on the shaft S′, and on the same shaft are also keyed 2 other cams, to which is attached by 2 chains the balance weight C W. On the same shaft are keyed a large wheel, and 2 drums, to which are attached, on opposite sides, the 2 water buckets B B′, for the purpose of aiding, if required, the manual power in working the lift. The balance weight C W is nearly equal to the weight of the caissons in the water, when working through the shortest leverage of the cams; the caissons being allowed a little weight in excess, in order that they may freely sink to the bottom of the water. The balance weight, when acting through the longest leverage (as shown by the dotted lines), is equal to balance the caissons when out of the water, and full of water; this weight of the caissons being the same under all circumstances, on account of the relative displacement of water, whether they

(1) An inclined plane for passing boats from one level to another, invented by Mr. J. Underhill, is represented and described in the article *Canals*, in Hebert's Engineer's and Mechanic's Encyclopædia. 1838.

(2) Rudiments of Civil Engineering, Part II., published in Weale's Rudimentary Series. In this valuable little work is a tolerably full description of Mr. Green's lift, accompanied by two illustrative engravings.

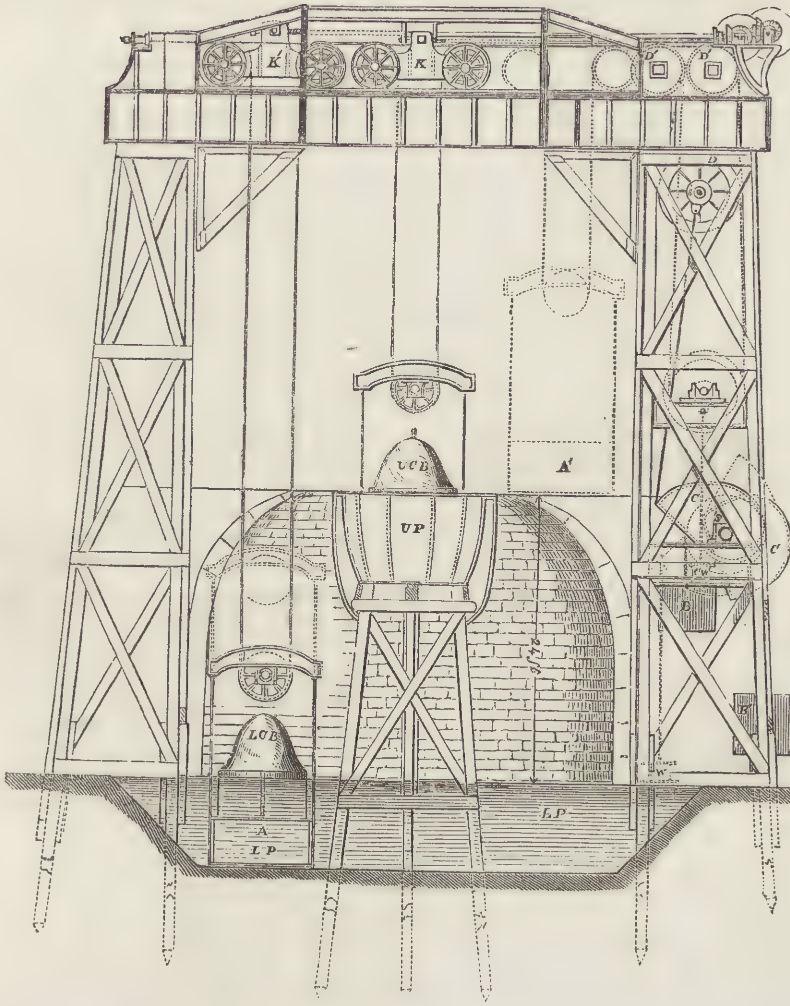


Fig. 1511. END ELEVATION OF MR. SLATE'S CANAL LIFT.

contain a loaded boat or an empty one, or are merely filled with water without any boat. The form of the cams between these two extreme points is regulated by the form and depth of the caissons.

The following is the action of the lift:—Supposing 2 loaded boats approaching the lift, one on the upper and the other on the lower level of the canal (the same description applying to empty boats, or to a single boat), each boat is floated into a position over the sunk caisson. The caissons with the boats floating in them are then raised out of the water by applying power to turn the shaft S′, by which the chains are wound on the cams, causing the upper shaft S, with the drums and suspending chains, to move down in the framework to the position shown by the dotted lines, Fig. 1511, thus raising the caissons and boats out of the water. This operation may be performed either by manual power or by means of the water buckets B B′, by turning on water from the upper level into the descending bucket, and letting out the water by a valve when the bucket reaches the bottom. The varying weight of the caissons, as they are being raised from the bottom to the surface, and then out of the water, is allowed for, so as to preserve the equilibrium throughout the operation, by the varying leverage of the balance weight acting upon and through the 4 cams; so that the power has no more than the friction of the machinery to overcome.

Having lifted both caissons out of the water, that which is required to descend to the lower level is moved across the canal, by means of the railway R R on the top of the framework, in a manner similar to that of an ordinary traversing crane, until it is suspended over the lower branch of the canal, ready to descend, as shown by the dotted lines. When in this position, the equilibrium is disturbed by allowing the water to escape from a small partition in the lower caisson; the shaft is also caused to revolve, and this by unwinding the chains attached to the descending caisson, and winding up the ascending one, carries

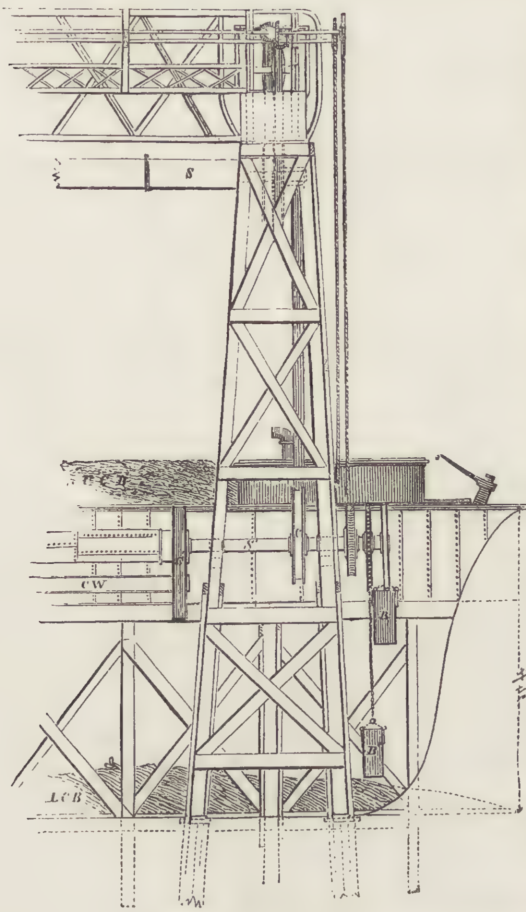


Fig. 1512. SIDE ELEVATION.

which this equilibrium lift may be applied, is limited only by the strength of materials and the convenience of working.

In the present system of locks, the amount of traffic on canals is limited to the supply of water, and this in many cases is not sufficient for the ordinary traffic; so that any reduction of the present rates of carriage on canals under the present system becomes hopeless.

This equilibrium lift may be made single or double. In its double form, as shown in the figures, it is estimated that it would pass one boat up and another down in about 3 to 5 minutes, according to the height of the lift. The value of this lift is its capacity for an almost unlimited amount of traffic, without any expense of water. Supposing the proposed plan to be applied to those canals where a number of locks, from 16 to 30, are situated close together, the loss of time to every boat in passing such a series, is from $2\frac{1}{2}$ to 5 hours; whereas, if one or two lifts were applied instead, the whole time required for a boat to pass would be only from 10 to 20 minutes. With regard to the expense of the lift, the inventor states that for a height of about 24 feet or 3 ordinary locks, the lift would be as cheap as locks: for a less height the comparative expense would be greater; but for a greater height, within reasonable limits, the lift would be considerably cheaper than locks; each additional 6 feet above the 24 feet costing from 200*l.* to 250*l.* In cases where it might

them to a relative position opposite to that from which they started; and they are stopped at the proper point by the adjusted length of the chains. The caisson which has been raised from the lower level is then moved as before, by means of the railway, across the bank of the canal, and suspended over the upper branch; the power again applied to the shaft conveying the cams with the balance weight; and the caissons are simultaneously lowered to the bottom of the canal, and the boats, floated over their ends, proceed on their journey.

In this plan there is obviously no waste of water; since the water consumed in the upward trade is equal to the tonnage of the ascending trade; and in the opposite direction the water supplied to the upper pounds of the canal is equal to the tonnage of the descending trade; so that a weight of water equal to the whole downward tonnage will be transferred from the lower to the higher levels of the canal. The difference of the levels of the two branches of a canal to

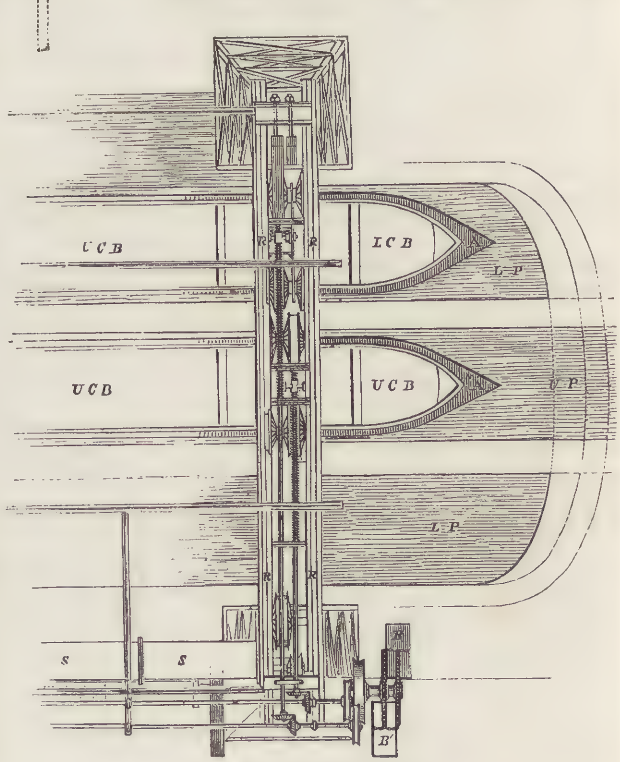


Fig. 1513. PORTION OF PLAN.

be desirable to transfer the boats through a great height, they might be passed at one lift through a shaft into a tunnel below, at any depth that might be required.

Throughout this description the loss of water is said to be nothing on the supposition that the lift is worked by the boatman's horse, or by manual power; but if water be used to work it, there will not in any case be required more then 10 per cent. of what is used in the present system of lockage, so that the results may be said to be practically the same, as no canal can possibly increase its trade tenfold.

The following table gives the length and dimensions of a few of the English and American canals:—

Name of Canal.	Date of construction.	Length in miles.	Breadth.		Depth.	Engineers.
			Top.	Bottom.		
ENGLISH.			feet.	in.	ft. in.	
Sankey Canal ...	1755	12	48		5 7	
Leeds and Liverpool.........	1770	$108\frac{3}{4}$	42	27	5 0	Brindley.
Basingstoke	1778	37	38		5 6	
Thames and Severn	1783	30	42	30	5 0	R. Whitworth.
Gloucester and Berkeley	1793	$16\frac{1}{2}$	70		18 0	Telford.
Grand Junction	1793	90	43		5 0	Jessop.
Kennet and Avon	1794	57	44	24	5 0	Rennie.
Aberdeenshire ..	1796	$18\frac{1}{2}$	23		3 9	Capt. Taylor.
Thames and Medway	1800	$8\frac{1}{2}$	50	28	7 0	
Caledonian	1803	23	40		20 0	Telford.
Rye, or Royal Military	1807	30	72	36	9 0	Royal Engineers.
AMERICAN.						
Champlain		11	40	28	4 0	
Schuylkill Navigation		58	36	22	3 6	
Morris		$101\frac{3}{4}$	32	20	4 0	
Pennsylvania ...		$276\frac{1}{4}$	40	28	4 0	
Erie		363	40	28	4 0	

NEEDLES. The manufacture of needles in ancient times, or among uncivilized nations at the present day, exhibits a rude attempt to form, in bone, ivory, or bronze, an instrument by which the sewing or stitching together of garments could be effected. The Esquimaux women, with their clumsy needles of bone, and with thread formed of the sinews of the reindeer, or the swallow-pipe of a species of seal, split into different sizes, manage to sew and stitch together with considerable neatness their deer-skin dresses and their water-tight boots and shoes. A rude kind of needle or bodkin, either of bone or ivory, has been found in British barrows; while needles of bronze, both for sewing and knitting, are preserved in museums, and are mentioned by Pliny as having been in use in his day. The early history of needles in our own country appears to be lost, but the introduction of fine steel needles, called "Spanish needles," and their manufacture in England, in the time of Queen Elizabeth, by Elias Crowse, a German, are chronicled by Stowe, who also states that, in Queen Mary's time, "a negro made fine Spanish needles in Cheapside, but would never teach his art to any." After the death of this negro (who by another writer is called "a native of India"), the art appears to have been lost sight of, but was again recovered in 1650 by Christopher Greening, who settled, with his three children, at Long Crendon, in Buckinghamshire. It must not be supposed, however, that the articles then called "fine steel needles" were more than a rude approach to the form and perfection of needles at the present day.

The English needle-manufacture is carried on principally at Redditch, a picturesque village in Worcestershire, situated about 14 miles from Birmingham. The circumstance of this village having become the seat of the manufacture is unaccounted for: no local traditions, as far as we could ascertain, assign a cause for it; yet from this obscure place, in the midst of an agricultural district, a large portion of Europe and of the British colonies, as well as our own country, is supplied with needles.

There are about a dozen principal factories or needle-mills in Redditch, in which the various processes of the manufacture are carried on. These factories are, like most others, large, well-lighted buildings, supplied with steam or water power, for giving motion to the wheels and apparatus concerned in the grinding and polishing of the needles. Many of the processes are, however, done by hand, and some of them at the cottages of the workpeople,—processes which enhance the value of the raw material in a wonderful degree, so that some of the finest needles are really "worth their weight in gold."

The raw material, as received from Birmingham or Sheffield, consists of soft, clean steel wire, in coils of various sizes and weights, and numbered to correspond with certain slits in a small steel plate, called a guage. Of these numbers, 1 represents a wire $\frac{1}{22}$ of an inch in diameter, and so on in diminishing proportion until 12 represents a wire $\frac{1}{100}$th of an inch in diameter. The first process in the manufacture is to take the wires from a number of coils of equal diameter, and, collecting them in the hand, to insert them between the blades of a pair of shears, and so cut them into successive lengths, each length being sufficient to make two needles. The shears are fixed to the wall in the cutting-room, and are pressed together by the workman's thigh. The number of pieces collected depends on the size of the wire: supposing the size No. 6 is being made, enough wire is uncoiled to cut up into 25,000 or 30,000 pieces, each piece being about three inches long, or the length of two needles. The pieces are all more or less bent, from having been coiled, and they must be straightened before any other operation takes place. For this purpose, several thousand pieces are collected within two broad and heavy rings, and are thus placed on a shelf in the furnace, and heated to redness. They are then lifted out, and placed on an iron plate, still retaining their position within the rings. A workman then takes what is called a *smooth file*, the form of which is shown in Fig. 1514, and placing the centre portion in the space between the rings, rubs or rolls the wires backwards and forwards, until by their friction against each other they are effectually straightened. The noise resembles that of filing, but soon changes from a grating sound to a more subdued

tone, which informs the workman that the necessary *rubbing*, as this process is called, has been effected.

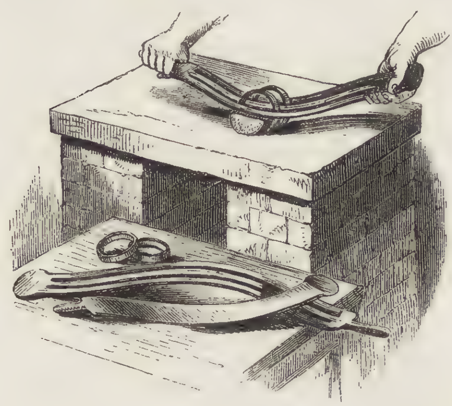


Fig. 1514.

The next process is one which injuriously affects the health of the operatives; but which may be rendered less hurtful by the adoption of recent improvements. It consists in grinding the two ends of the straightened wires upon small grit stones of from ten to twenty inches in diameter, according to the size of

Fig. 1515. POINTING THE WIRES.

the needle. These grindstones are set in rapid motion, while a workmen seated before each, takes a number of wires in his left hand and spreads them out, keeping them parallel by placing the right hand upon them in a peculiar way, and at the same time moving it so as to make all the wires rotate backwards and forwards in order that a perfect cone or point may be formed. Sometimes a piece of stout-leather, called a *thumb-piece*, is used in pressing the wires against the stone. Occasionally he adjusts the points, and also dips them in water to keep them cool, for when the points are in contact with the stone the friction produces heat and a brilliant stream of sparks. The minute particles of grit and of steel which thus fly off into the air form a dust which enters the workman's lungs and produces an affection of the breath, known as *grinder's asthma.* This disease, when aggravated by intemperance, as is too often the case, becomes early fatal, so that the man is old at thirty, and frequently dies at thirty-five or forty. Several ingenious inventions have been contrived to make his trade less hurtful, but in the great majority of instances the grinder refuses to adopt them, under the idea that his wages will be lowered if the risk is lessened. Thus he voluntarily destroys his health for the sake of high wages, using no other precaution than a handkerchief tied over his mouth, and forgetting that skill of the kind he possesses would always meet with a fair reward, and that freedom from much pain and suffering would also result from the use of the means set before him. One of these means is afforded by a mask for covering the mouth and nostrils, in which two or three layers of crape or muslin are stretched over a slight wooden frame, which is studded with magnets. These attract the particles of steel in the passage to the mouth, while the crape filters the air of particles of grit. As the mask becomes loaded with particles it is necessary to take it off once or twice in the course of an hour and give it a few gentle taps. This apparatus is tolerably effective, and has been invented more than thirty years, yet the grinders continue to reject it for the reason above named. Another piece of apparatus is the ventilating shaft noticed under CUTLERY, leading from the grindstone through the wall of the grinding room into the open air. In this pipe a strong current of air is generated by a fan, the effect of which is to draw away the particles of steel and grit from the grindstone as soon as they are formed, and convey them at once into the open air. But this was also neglected. It is therefore with sincere pleasure we record the humane conduct of the principal needle manufacturers, who seeing the workmen themselves thus suicidal in their conduct, have taken steps for doing them good against their will, and have introduced ventilating shafts for clearing the air of this pernicious dust.

When the needle, or pair of needles, leaves the grinder it is a straight piece of soft dingy wire, pointed at each extremity. The next process is the formation of two eyes in the centre. The eye of a needle consists of a small groove and a perforation, and these must be formed by successive and cautious operations, that the wire be not damaged in the process. The grooves, and a small indentation at the spot intended for the hole are first produced by the stamping machine. This is a bed of iron containing the under half of a die or stamp, supported on a heavy block of stone. Above this is a hammer of about twelve pounds weight, containing the other half of the die, and capable of being raised by pressing a lever with the foot. The workman, holding several wires, or blank needles, drops one at a time upon the iron bed, pushing it up against a piece of metal so as to determine the length of the needle; then, raising the hammer with his foot, lets it fall with a smart blow. The two raised faces of the die produce two opposite indentations on the wire, bulging out a portion of its substance. Although the stamper has to

adjust and stamp each wire separately, yet he can operate upon two thousand wires, equivalent to four thousand needles, in the course of an hour.

The task of piercing the eyes is committed to a number of boys, who work small hand-presses provided for that purpose. Spreading the wires out like a fan, the boy places one of them in a notch formed in a small iron slab, Fig. 1516, bringing the middle of the wire to the middle of the press. The upper arm of the press contains two steel points or cutters, of the exact size of the eye, which fall over corresponding holes in the die. The boy holding his head close to his work brings this arm down and cuts or punches out the eye. As each wire is pierced the boy shifts the fan of wires so as to bring a fresh wire under the punch. This is called *eyeing the needles;* but in some cases it is done in a different manner. For some kinds of needle the wires as soon as they are pointed at the two ends, are cut in the middle by means of the upright shears already noticed, and are then laid parallel to each other in small wooden boxes, and transferred to the head flattener. This is a workman, seated at a table, with a cubical block of steel before him, on which he flattens the head of each wire separately, with a small hammer, holding the wires spread out in his left hand, and presenting them in rapid succession, so that each blow of the hammer flattens one needle. This blow also hardens the ends of the wires, therefore it is necessary to soften them by heating and then slowly cooling, before they are given to the *piercer.* This is generally a child, who placing the ends on a block of steel applies the point of a small punch to each, and pierces the eye by a smart tap of the hammer; the needles are then turned over and the process repeated on the opposite side, that both sides of the eye may be alike. The eyes have next to be trimmed by another child, who inserts a punch in the eye, and while it is still sticking in it, taps the needle on each side with a hammer, so that the eye assumes the shape of the punch. The needle is then taken between pincers and the head rested in an angular groove cut in a piece of hard steel, when, with a single stroke of a small file on the two opposite sides of the head, the groove is formed. With a file also the head is rounded and smoothed. This finishes the shaping of the separate needles, but the forming of grooves and eyes in the double needle, as first described, is the most expeditious and economical method, and that which is generally adopted. Fig. 1517 represents, 1. The straight wire, pointed at both ends. 2. The same, flattened in the centre and grooved. 3. The same, with the eye perforated. The bur produced on each side of the eye in the process of stamping is filed off, not separately, but from a number at once, which are ingeniously spitted on fine wires, Fig. 1518, run through each line of eyes with great rapidity by children. When the whole have been acted upon by a flat file, the separation of the needles is effected, not separately but by bending the whole line of needles backwards and forwards between the two spits, thus producing two separate rows of needles, each row spitted on a wire. The points of each row are then grasped in a kind of hand vice, Fig. 1519, and the heads filed to their proper shape. After passing through all these processes some of the needles have necessarily become bent; they are therefore sent to the *soft straightener.* This is generally a woman, who, placing a number of the needles (which are still in the soft state) on a flat steel plate, rolls them backwards and forwards one at a time by means of a smooth steel file turned up at each end, so as to present a convex surface to the needles. Two or three turns of the file to each needle are sufficient to straighten it, and the woman can thus operate on a thousand needles per hour.

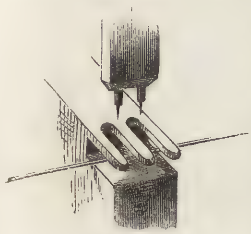


Fig. 1516.

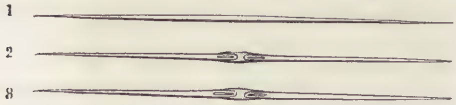


Fig. 1517.

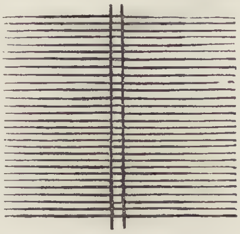


Fig. 1518.

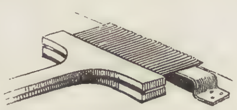


Fig. 1519.

Still, however, the needles are far from complete, for they are black, dingy, and soft. In order to harden them, they are spread by means of 2 little trowels, in a thickish layer on narrow plates of iron, and placed on a shelf in the furnace. When they have reached a red heat, they are taken out, and suddenly cooled by being plunged into cold water or oil. This makes them too hard and brittle for use; therefore, they are next *tempered,* that is, when taken out of the water and dried, they are again heated, but not to so high a temperature, and are allowed to cool gradually. The method of heating is on an iron plate with a fire beneath, and the needles are kept in constant motion with small iron shovels until a blue oxide forms upon them, when they are considered to be of the proper temper, and are instantly removed. In the process of hardening, some of the needles again become bent; so that the next process is *hard* or *hammer straightening,* which is usually done at the homes of the workpeople. The needles are rolled by the finger on a smooth steel slab, to detect those which are bent, and so do not roll truly; these are picked out, and straightened by hammering on a small anvil.

The needles being hardened, have next to be *scoured* or cleaned. This is effected, principally, by mutual attrition. They are made up into bundles of 40,000 or 50,000 in the following manner:—A number of

strings are laid across a wooden tray open at both ends, Fig. 1520; upon these strings is placed a stout piece of canvass, and within the canvass the needles are arranged in heaps in the direction of their length, but without any distinction as to heads or points. A small quantity of emery, oil, and soft-soap is sprinkled over them, and they are then rolled up in a bundle, and tied up temporarily. A man then winds a piece of strong twine round the bundle in a tolerably close coil, removing the string as he advances with the twine, and forming at length a compact bundle 2 or 3 feet long, and 3 or 4 inches thick. When a number of such rolls have been prepared, they are placed under scouring-machines, Fig. 1521, which consist of troughs containing weighted slabs, under which the bundles of needles are moved backwards and forwards in the same way as the rollers of a common mangle. The rubbers work at the rate of 20 or 30 movements in a minute, pressing heavily on the rolls, and causing the needles to rub over and over each other, so that by constant friction, aided by emery, oil, soft-soap, and polishing putty, during 50 or 60 hours, a bright surface is obtained. The rubbing is suspended every 8 hours to renew the canvass, which becomes worn through, and to add fresh polishing putty and oil, the needles being also washed in soap and water on each occasion. For the best needles this process is carried on during 7 or 8 days in succession, and the breakage is often considerable.

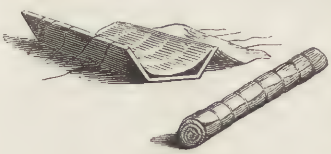


Fig. 1520.

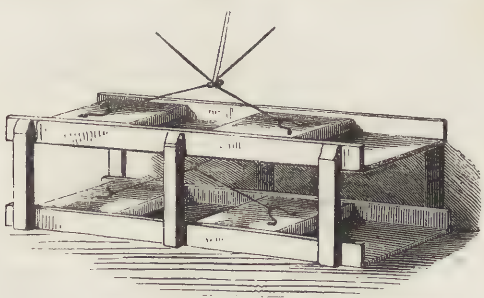


Fig. 1521.

The bright and clean needles are next sent to the *bright-shop*, where they are shaken in long tin trays till they all lie parallel, then made up into long rows or heaps, and passed to a little girl called the *header*, whose task it is to turn all the heads one way. Difficult as this may seem where 40,000 or 50,000 needles are concerned, it is done with a degree of rapidity and ease which astonishes by its simplicity. The child has a piece of rag or soft leather wrapped round her fore finger, and pressing it against the pile of needles, all the points which happen to lie that way run into the rag, and retain sufficient hold to allow of her drawing the needles in this way out of the heap, and depositing them in a new pile, so that when the work is done, the needles form two large heaps with the points lying in opposite directions. Broken or defective needles are rejected from these heaps, and the remainder are subjected to the delicate operation of having the sharp edges of the eye removed which are so apt to cut the thread. This is called *drilling*, and in order to its proper performances, the needles have again to be annealed about the eye. This is done by placing them on a steel plate with their eyes projecting over its edge. A red-hot plate is then cautiously brought near them, and when they assume a dark blue colour, the proper temper is acquired. The drilling is performed by young women seated at a bench opposite a window, and having each a small three-sided steel drill in rapid revolution before her. The driller taking up a few needles, and spreading them out like a fan, brings them in succession under the action of the drill. Each eye is first countersunk, that is, its sharp edge is bevelled off with the drill, so as to join the groove in a rounded instead of an angular manner. The rest of the eye is also drilled on both sides, and made perfectly smooth. This drilling, which is of modern invention, is a great improvement in the manufacture; but it is almost painful to witness, from the peculiar constrained posture, and rigid look of the persons employed on it—so necessary is it in this delicate operation to prevent the least tremor or unsteadiness of hand. Gold-eyed needles are produced by dipping the head of the needle in ether containing gold in solution, which immediately attaches itself to the steel. This merely serves to increase the cost of the needle without adding to its utility.

Fig. 1522. DRILLING THE EYES.

After the drilling, the needles have their points finished on a small and rapidly rotating hone-stone. They are then passed to the polisher, who polishes them on wheels of wood covered with buff leather slightly smeared with polishing paste. They are then ready for papering, for which purpose they are counted into quarters of hundreds, folded up in blue paper, and labelled. These papers are then made up in bundles of 20 each, and these again into square *packets*, which may contain 20,000, 40,000, or 60,000 needles. When intended for exportation, they are packed in soldered tin cases. The processes above described apply to the fine sorts of needles, for the common kinds several of the finishing operations are omitted. At the mill visited by the

writer, 100,000,000 fine needles are made in the course of a year, while the total amount produced at Redditch and the neighbourhood, is 70,000,000 per week.

NET. See WEAVING.

NEUTRAL SALTS. When an acid and a base are combined in certain definite proportions, they *neutralize* each other's properties, so that neither the acid nor the alkali, if the base be an alkali, exerts any action on test-papers: the result is what is called a *neutral salt.* The proportions, or *equivalents,* as they are called, in which bodies neutralize each other are very variable. "Some acids have very high capacities of saturation; of others a much larger quantity must be employed to neutralize the same amount of base. The bases themselves present also similar phenomena. Thus, to saturate 47·19 parts of potash, or 116 parts of oxide of silver, there are required 40·09 parts of sulphuric acid; 54·06 of nitric acid; 75·41 of chloric acid; 166·36 of iodic acid; and 51 of acetic acid: numbers very different, but representing quantities which replace each other in combination. Now, if a quantity of some base, such as potash, be taken, which is represented by the sum of the equivalents of potassium and oxygen, then the quantity of any acid requisite for its neutralization, as determined by direct experiment, will always be found equal to the sum of the equivalents of the different components of the acid itself. Thus 39·19 = the equivalent of potassium + 8 = the equivalent of oxygen = 47·19, the assumed equivalent of potash; and 47·19 parts of potash are found to be exactly neutralized by 40·09 parts of real sulphuric acid, or by 54·06 of real nitric acid. These quantities are evidently made up by adding together the equivalents of their constituents:—

1 equiv. sulphur	= 16·09	1 equiv. nitrogen ...	= 14·06
3 „ oxygen	= 24.	5 „ oxygen	= 40·
1 equiv. sulphuric acid	40·09	1 equiv. nitric acid	54·06

The same is true if any acid be taken, and the quantities of different bases required for its neutralization determined: the combining number of the compound will always be found to be the sum of the combining numbers of its components, however complex the substance may be." [1]

NEUTRALIZATION. See ALKALIMETRY.

NEUTRIA. See HAT—FUR.

NICKEL (Ni 29·57), a metal of a greyish white colour, with remarkable magnetic properties, which it loses on being heated to 660°. It is ductile and malleable: a Bavarian coin has been struck in nickel, and the impression of the die is said to be very perfect. The sp. gr. of nickel varies from 8·27 to 8·40 when fused, and after being hammered, from 8·69 to 9·0. It has a high melting-point, and is but little acted on by dilute acids. Heated in contact with air, it acquires various tints like steel, and becomes soon covered with a green oxide. The pure metal is easily prepared by raising the oxalate to a white heat in a crucible lined with charcoal. Native nickel is found in the Erzgebirge in small quantities. *Kupfernickel* or copper nickel is an arseniuret, and is tolerably abundant; but some of the arsenic is occasionally replaced by antimony. Copper nickel is usually associated with the ores of copper, silver, and cobalt, and is chiefly obtained from the mines of Saxony. The old German miners regarded it as a kind of false copper, and applied the term *nickel* to it by way of contempt. It has also been found in Cornwall. Among the other ores are *nickel glance,* an arsenical ore, found massive and in cubical crystals; *white nickel,* another arsenical ore; *nickel stibine,* an antimonial sulphuret of nickel; *antimonial nickel,* containing no sulphur: it is of a pale copper colour. *Nickel pyrites* is a sulphuret, of a brass yellow colour, containing 64 per cent. of nickel: *nickeliferous pyrites* is a double sulphuret of iron and nickel, of a bronze yellow colour: there is also a sulphuret of nickel containing bismuth. An alloy of iron and nickel forms a principal metallic ingredient in most aërolites or meteoric stones.

(1) Fownes' Manual of Chemistry. See also Regnault, Cours de Chimie, ii. p. 50, 2d Edition.

Nickel forms two oxides only, one of which is basic. The protoxide, NiO, may be prepared by heating the nickel to redness, or by precipitating a soluble salt with caustic potash: the apple-green hydrated oxide is to be washed, dried, and ignited: the resulting protoxide is an ash-grey powder, freely soluble in acids, which it completely neutralizes: the salts have usually a beautiful green colour. Sulphate of nickel is the most important of the salts of nickel. It forms green prismatic crystals, containing 7 equivalents of water, which require 3 parts of cold water for solution. It forms beautiful double salts with the sulphates of potash and ammonia.

Pure salts of nickel may be prepared on a small scale from crude *speiss,* or kupfernickel, by the following process: "The mineral is broken into small fragments, mixed with from one-fourth to half its weight of iron filings, and the whole dissolved in aqua regia. The solution is gently evaporated to dryness, the residue treated with boiling water, and the insoluble arseniate of iron removed by a filter. The liquid is then acidulated with hydrochloric acid, treated with sulphuretted hydrogen in excess, and after filtration boiled with a little nitric acid to bring back the iron to the state of peroxide. To the cold and largely diluted liquid, solution of bicarbonate of soda is gradually added, by which the peroxide of iron may be completely separated, without loss of nickel salt. Lastly, the filtered solution boiled with carbonate of soda in excess yields an abundant pale green precipitate of carbonate of nickel, from which all the other compounds may be prepared."—*Fownes.*

The nickel of commerce is obtained chiefly from kupfernickel, nickeliferous pyrites, and from the speiss obtained as a secondary product in the treatment of the nickeliferous ores of cobalt. As there is a great demand for nickel in the manufacture of German silver, some improved methods of obtaining the metal have lately been introduced. They are kept secret; but Mr. Phillips in his Manual of Mineralogy suggests the following as the process likely to be followed:—"The roasted ore or speiss, after being dissolved either in sulphuric or hydrochloric acid, to which either

nitric acid or nitrate of soda has been added to peroxidise the metals, is placed in large vessels in which the insoluble matters are allowed to subside. The clear liquor, after it has cooled, and the copper and lead which have been precipitated by sulphuretted hydrogen, may be decanted off, and treated by carbonate of lime in the form of common chalk, by which the iron and traces of cobalt will be precipitated, whilst the greater portion of the cobalt and the whole of the nickel will remain in solution. After the oxide of iron thus precipitated has subsided, and the liquor has been again syphoned off, the cobalt may be thrown down by saturating the solution with chlorine gas, by the addition of hypochlorite of lime, and then adding carbonate of lime or carbonate of baryta. The liquor syphoned from this solution contains the whole of the nickel, which may now be precipitated by ebullition with hydrate of lime, and dried and reduced in the usual manner."

As nickel is used entirely as an alloy, it is sent into the market in the form of finely divided grains, or granulations of the size of small beans. [See SILVER, GERMAN.]

NICOTINE. See TOBACCO.

NIELLO. A kind of enamelling, practised, according to some writers, as early as the seventh century, but afterwards lost until Finiguerra, an eminent goldsmith of Florence, brought it into great repute in the 15th century. The art is interesting, as it is supposed to have given the first idea of printing from engraved plates. It consists in engraving a subject on gold or silver, and filling the engraved lines with black or very dark-coloured enamel. In the general effect of works in niello, there is considerable resemblance to damascening, except that in the latter the engraved lines were filled up with the precious metals, while, in the former, a paste or enamel was made use of. This enamel was a compound of silver, copper, lead, sulphur, and borax, forming a dark-coloured paste, which was carefully worked into all the lines of the engraving, and fused, by heating the plate. It contrasted favourably with the bright surface of the silver chalice or other article so decorated, producing an effect not unlike that of a copper-plate engraving, or of a daguerreotype. This kind of work, at one period, constituted the favourite means of adorning, not only all kinds of vessels used for sacred purposes, but also sword-hilts, knife-handles, and other articles in which the precious metals formed the basis to work upon. In the Museum, at Florence, is the most valuable specimen of ancient niello now existing, being a plate for a pix executed by Finiguerra himself in 1452. An interesting specimen is to be seen in the British Museum, consisting of a silver cup mounted in gold, the ornaments being in niello. This long-neglected art has been revived and again brought into notice, by a silversmith of Berlin, named Wagner, who is now settled in Paris. A very successful work in niello was sent by the Messrs. Gass, of Regent-street, London, to the Great Exhibition. It was a silver gauntlet niello bracelet, designed by D. Maclise, Esq., R. A., descriptive of "The Promised Gift," "The Gift Ordered," and "The Presentation," interlaced with decorative illustration. This elaborate design was engraved by Mr. J. J. Crew.

Artists in niello find it necessary to take proofs of their work as it proceeds, and so in ancient times it is stated that the work was examined by filling the lines with a black fatty material, and then pressing a mass of a peculiar kind of clay upon the design, so as to obtain an impression. This process so nearly resembled printing, that it is only to be wondered at that the latter art was not earlier discovered. It is said that the important secret was at last revealed by a female accidentally placing a bundle of damp linen on a niello plate which had been proved in the workshop of Finiguerra, and which happened to be lying with some of the black material still remaining in the lines. The damp linen absorbed the black, and gave a perfect impression of the plate to the astonishment and delight of Finiguerra, who immediately instituted a series of experiments which ended in the discovery of the engraver's art.

NITRE. See POTASSIUM.

NITRIC ACID. See NITROGEN.

NITROGEN (N 14), one of the constituents of the atmosphere, of which it forms about $\frac{4}{5}$ths. [See AIR.] It also enters into the composition of a large number of substances, such as the native nitrates or nitres, whence the term *nitrogen*, *i. e.* generator of nitre. It occurs in coal and a few minerals, and is frequently found in animal and vegetable substances. It may be prepared for the purposes of experiment by burning out the oxygen from a confined portion of air by means of phosphorus, or by a jet of hydrogen. There are various other methods of preparing it, for which we must refer to chemical treatises.

Nitrogen has no colour, taste, or smell: its density is ·972, or a little lighter than air: 100 cubic inches at the temperature of 60°, and the pressure of 30 inches, weigh 30·14 grains. This gas is not capable of supporting animal life, and hence it was termed by Lavoisier, *azote* (from ἀ, privative, and ζωή, life), a name which it still retains among French chemists: it does not appear to have any poisonous properties: animals die in it from the absence of oxygen, and flame cannot burn in it from the same defect. Nitrogen is not soluble to any extent in water or caustic alkali; it is, in fact, most remarkable for its negative properties. It is seldom used in its pure state; but, being without action upon other substances, it may be employed for forming artificial atmospheres for protecting certain bodies from the action of oxygen or other active gases.

The compounds of nitrogen and oxygen are of importance. Of these there are not less than five:—

	Nitrogen.	Oxygen.
Protoxide of nitrogen	14	8
Deutoxide of nitrogen	14	16
Hyponitrous acid	14	24
Nitrous acid	14	32
Nitric acid	14	40

Of these compounds nitric acid is the most important, and as it is by means of it that all the others are prepared, it is desirable to notice it first.

Nitric acid, NO_5, is prepared by the chemist from nitre or saltpetre, which is a compound of nitric acid and potash. Equal weights of powdered nitre and sulphuric acid are introduced into a glass retort to which heat is applied: the beak of the retort is introduced into a flask, or glass receiver, kept cool by a wet cloth. The sulphuric acid unites with the potash to form bisulphate of potash, which remains in the retort, while the nitric acid combines with the water of the sulphuric acid and distils over.

In the manufacture of nitric acid on a large scale, cast-iron cylinders are commonly used with earthern condensing vessels connected by tubes as receivers. The iron cylinders are arranged in pairs, as shown in Fig. 1523. In front of each cylinder is an opening,

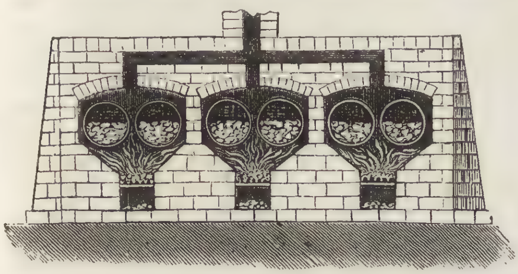


Fig. 1523. NITRIC ACID IRON RETORTS.

to which one end of a bent tube, *t*, Fig. 1524, is luted, the other end passing into the neck of the first receiver W. The tube *t′* from the middle neck is connected with the middle neck of the next receiver; while the

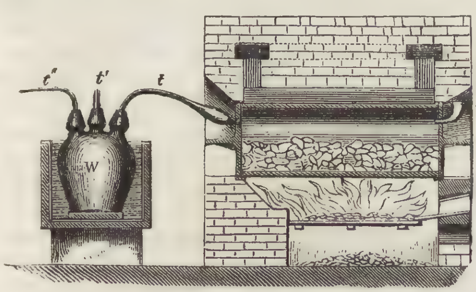


Fig. 1524. SIDE ELEVATION

tube *t″* from the third neck passes to a series of two-necked Woulfe bottles, arranged as shown in Fig. 717, DISTILLATION. Thus the two cylinders of each fire discharge their fumes into two series of receivers, which are connected together at the commencement of the series. The cylinders are charged with nitrate of potash, or nitrate of soda, which is also used for the purpose, by removing the back plates, which, being restored, a quantity of strong sulphuric acid is poured in by means of a cast-iron funnel, *f*, the beak of which is inserted into an opening which is afterwards closed with a stopple of baked clay. The joints are then carefully luted, and the heat applied in a regular manner, until the acid ceases to distil over. The plates are then removed, and the sulphate of potash drawn out by means of iron scrapers. The acid, condensed in the first receivers, is the most impure: it is contaminated with sulphuric acid carried over in the distillation. This impure acid is employed in the manufacture of sulphuric acid. The other receivers contain the nitric acid of commerce. It is of variable strength, and contains a certain amount of nitrous acid, and sometimes a little chlorine, if the nitre contain minute portions of chlorides. The last receivers in the series contain only a weak acid. At the commencement of an operation this weak acid is usually poured into the first receivers, and pure water into the last receivers for the purpose of completely condensing the nitrous vapours. The acid of commerce, thus prepared, is usually sufficiently pure for most purposes: but it may be freed from chlorine and sulphuric acid by agitating it with a little concentrated solution of nitrate of silver, and redistilling in a glass retort.

Nitric acid is also prepared on a large scale in glass or earthenware retorts, arranged in a *gallery furnace*, as shown in Fig. 1525, in which the retorts are sunk

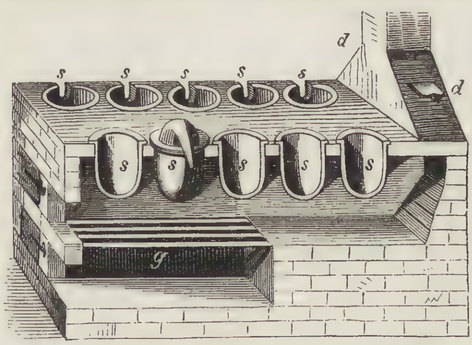


Fig. 1525. NITRIC ACID GALLERY FURNACE.

in sand pots *s s*. The furnace has two fires with one chimney, furnished with dampers *d d*, a thin partition being placed between them; *g* is the grate, the fire from which traverses the whole length of the furnace, and heats the sand pots. The fire can be moved into such a position as will distribute the heat uniformly. The retorts must be charged with care, to prevent any sulphuric acid from wetting the necks, for which purpose a long funnel is used. The receiver adapted to each retort is kept cool by a stream of cold water, or a very large receiver is employed, such that the action of the ordinary temperature of the air is sufficient to condense the fumes. When the first impure portions of acid have been collected, fresh receivers containing water are substituted so as to keep the purer acid separate.

The nitric acid of commerce is also called *aqua-fortis*, without reference to its strength. That in common use contains about two-thirds water: what is called *double aqua-fortis* contains 40 per cent. of water, and is of the sp. gr. 1·42, its boiling point being 248°. Acid is commonly met with of a sp. gr. 1·50 to 1·52; it has a yellow colour in consequence of the presence of nitrous or hyponitrous acid. It is exceedingly corrosive. When poured upon red-hot charcoal it produces brilliant combustion, and when added to warm oil of turpentine it sets it on fire. The pure acid is quite colourless: it has a sp. gr. of 1·517 at 60° Fahr. and boils at 184°. It consists of 54·06

parts of real acid, and 9 parts water: the anhydrous acid has been unknown until recently M. Deville has obtained it by the action of dry chlorine on nitrate of silver, the utmost care being taken to exclude moisture: chloride of silver is formed, and anhydrous nitric acid evolved.[1] Nitric acid requires to be diluted before it will attack metals, and its action on lignine, starch, &c. is much less energetic than that of an acid containing more water. There is a second definite compound of real nitric acid and water, containing 54·06 parts of acid and 36 of water: its sp. gr. at 60° is 1·424, and it boils at 250°. An acid weaker than this may be concentrated to it by evaporation, and a stronger acid may be reduced thereto by loss of nitric acid and water in the form of the first hydrate.

Nitric acid is formed in minute quantities by passing a stream of electric sparks through a confined portion of air, water or an alkaline solution being present. It is probable that nitric acid is formed in this way during thunder storms: the lightning striking through vast masses of atmospheric air may cause the oxygen and nitrogen to combine in proper proportions, and this acid, uniting with the ammonia also found in the atmosphere, may descend with the rain upon the earth in the form of nitrate of ammonia.

Nitric acid forms with bases an extensive group of salts, the *nitrates*, which are all soluble in water. This circumstance renders the detection of nitric acid in small quantities in solution somewhat difficult, since no precipitant for it can be found. One of the best tests is its power of bleaching a solution of indigo in sulphuric acid when boiled therewith. Chlorine must of course be absent. The hydrated acid is of importance to the chemist, the pharmist, and the manufacturer. It imparts a yellow colour to many animal substances, and is hence used for producing yellow patterns upon coloured woollen goods. It is used as a solvent for tin in the preparation of mordants: it is employed for etching on copper: it is of importance in metallurgy and assaying. It is administered in a dilute form in medicine, and it is an energetic caustic in surgery. Professor Brande suggests, that if effectually applied to a wound occasioned by the bite of rabid animals, it might destroy the poison and prevent its consequences. The remedy, however, to be effectual, must be applied speedily after the injury.

The other compounds of nitrogen and oxygen are, as already stated, prepared from nitric acid, or the nitrates. The *protoxide of nitrogen*, or *nitrous oxide*, NO, is prepared by distilling pure nitrate of ammonia in a glass retort: the salt is resolved into nitrous oxide and water. It is a colourless invisible gas, with a faint agreeable odour, and a sweetish taste. Cold water dissolves about $\frac{3}{4}$ths of its volume of the gas; hence it should be collected over warm water, which absorbs much less. It supports combustion with an energy inferior only to that of oxygen. When inhaled from a water-proof bag furnished with an ivory mouthpiece, it produces a strange kind of exhilaration, and occasionally a strong ungraceful muscular action, accompanied by laughter, which has an unpleasant unnatural effect, from the eyes not partaking in the joyous expression, but being usually rigidly fixed. This property has procured for nitrous oxide the name of *laughing-gas*.

(1) Annales de Chimie, III. Serie, Tome 28.

The next compound, *binoxide* or *deutoxide of nitrogen*, also called *nitric oxide*, NO_2, is prepared by the action of dilute nitric acid on clippings or turnings of copper. A portion of the nitric acid is deoxidized by the copper; the metal is oxidized and dissolved by another portion of the acid. The resulting gas, which may be collected over cold water, is colourless and transparent: it does not support combustion; but if phosphorus in a state of vivid ignition be introduced into a jar of it, it is decomposed, and the phosphorus burns vividly. The most remarkable property of nitric oxide is, that on coming in contact with air or oxygen it produces red fumes, which are absorbed by water.

Hyponitrous acid, NO_3, is prepared by mixing 4 measures of binoxide of nitrogen with 1 measure of oxygen: the gases must be perfectly dry, and exposed to the temperature of zero: they condense into a thin mobile liquid, which is colourless at that temperature, but green at ordinary temperatures: its vapour is orange red.

Nitrous acid, NO_4. The deep red fumes formed when binoxide of nitrogen is exposed to the air or to oxygen gas, consist of nitrous acid. By heating nitrate of lead, the nitric acid separates from the oxide of lead, and resolves itself into oxygen and nitrous acid. Under the influence of a powerful freezing mixture, the nitrous acid may be obtained in the liquid form: it is nearly colourless, but becomes yellow and red as the temperature rises. At 82° it boils, and gives off red fumes. This as well as hyponitrous acid is decomposed by water into binoxide of nitrogen and nitric acid. Strong nitric acid absorbs its vapour, and assumes a yellow or red tint, then green and blue, and as water is added all colour disappears. The red fuming nitrous acid of commerce is nitric acid impregnated with nitrous gas. Nitrous acid does not seem to have the power of forming salts with bases, and hence its title to the term acid has been questioned.

NITROMURIATIC ACID. See AQUA REGIA.

NUTMEGS and MACE. Both these spices are the produce of the same tree (*Myristica moschata*), a native of the Molucca Islands, but cultivated in Sumatra, Java, and elsewhere in the East. It is likewise cultivated in several of the West India Islands, but with less success. The fruit of the nutmeg-tree is as large as that of our peach; but when ripe the fleshy part bursts asunder in two halves, showing the stone (as we should call it in the peach) which contains within it the valuable kernel or nutmeg. But this stone is itself covered with a membranous kind of network, of a bright red colour, which is the mace: in drying this afterwards becomes orange yellow. The appearance of the rich brown shell of the nutmeg covered with the red fibres of the mace is very beautiful in the fresh fruit. These fibres being removed,

the shells are dried in the sun or by a moderate fire until they split, revealing the aromatic kernel or nutmeg.

Nutmeg plantations are formed in alluvial ground, or in virgin forest land in level situations. Declivities are unfavourable on account of the slight hold these trees take on the soil, and the consequent danger of their being uprooted during the heavy rains which occur in tropical countries. Their culture in Bencoolen, which represents the ordinary mode of treatment, has been minutely described by Dr. Lumsdaine, in a paper originally communicated to the Agricultural Society of Sumatra, in 1820, and recently republished in Silliman's American Journal of Science and Arts. From this account we learn that in originating a nutmeg plantation it is necessary to select ripe and sound nuts, and set them at the distance of a foot apart in a rich soil, covering them lightly with mould. They must then be watered every other day, weeded occasionally, and shielded from a scorching sun. In from one to two months the young seedlings may be expected to appear; and when about 4 feet high, the healthiest and most luxuriant are to be removed at the commencement of the rainy season to the plantation previously cleared and prepared for that purpose, and set at the distance of 80 feet from each other, care being taken to protect them from the heat and from violent winds. The plants are set in rows, and between these the plough is employed to clear the intermediate spaces of weeds and grasses, which in warm climates spring up in great luxuriance and choke the soil. The plants continue to require watering every other day in sultry weather; and in nearly all cases the soil requires to be enriched with annual supplies of manure, which are laid on during the rains, and which are made more stimulating as the tree increases in age. After the fifth year the trees no longer require to be shielded from the sun; in the seventh year they begin to bear fruit; and from that time to the fifteenth year they generally increase in fruitfulness, being then in their highest perfection.

During the progressive growth of the plantation, the beds of the trees are regularly weeded, and the roots kept covered with the mould, for these have a constant tendency to seek the surface: the growth of lateral branches is alone encouraged, and all suckers or dead and unproductive branches are removed by the pruning-knife, so as to thin the trees considerably, and admit of the descent of the night-dews, which contribute much to their well-being, especially during dry and sultry weather. The conclusion of the principal harvest is the time chosen for these prunings. As the trees advance in age, the coarser vegetation and creepers are alone removed from the intervals between the trees, and the more harmless grasses are allowed to remain, giving the plantation a park-like appearance. The use of the plough is then discontinued.

Nutmeg-trees are of two kinds in the same plantation, flower-bearing, and fruit-bearing. The productive plants are in the proportion of about two-thirds to the whole plantation. It is impossible to discover the difference in the sexes of the plants until the period of flowering. Between the appearance of the blossom and the ripening of the fruit, a period of 7 months generally elapses; but when once a tree has begun bearing, it continues to produce fruit all the year round, but more plentifully in some months than in others. The months of September, October, November and December, are the period of the great harvest; those of April, May, and June of the smaller harvest. In the Moluccas these trees continue prolific for 70 or 80 years; and the annual produce, taking one tree with another, amounts to about five pounds of nutmegs, and a pound and a quarter of mace for each tree.

When the fruit is ripe, which is indicated by the bursting open of the fleshy portion, and the appearance of the kernel, it is gathered in by means of long hooked sticks. The first step, after removing the outer integument, is cautiously to strip off the mace, and flatten it by hand in single layers placed on mats and dried for 3 or 4 days in the sun. In damp and rainy weather the heat of a charcoal fire is employed, but with care that no smoke or heat blacken the surface of the mace. In drying, the red tint of the mace changes to orange, its substance becomes horny and brittle, and its strongly aromatic odour and taste are preserved. When well cured, it is made up in tight packages in a dry situation; but is exposed to the sun about once a fortnight to preserve its dryness, and thus to keep it from insects which attack it if it becomes damp.

The nuts being liberated from their macy envelope, are conveyed to the drying house and placed on a raised stage or framework, which admits the heat from a smouldering fire beneath it, to pass freely among them. The heat is kept below 140° Fahr., because too great a heat dries up the kernels, while too long continued heat produces fermentation, which increases their volume so greatly as to fill up the whole cavity of the shell, and thus prevent them from rattling, which is the criterion of due preparation.

The drying-house is a brick building of suitable size, and the stage is placed at an elevation of 10 feet, having 3 divisions in it for the produce of different months. The nuts are turned every second or third day, that they may all partake equally of the heat, and such as have undergone the smoking process for the period of 2 complete months, and rattle freely in the shell, are cracked with wooden mallets, and the worm-eaten and shrivelled ones thrown out. The sound nutmegs are rubbed over with recently prepared well sifted dry lime, and packed tightly in chests, the seams of which have been made impervious to air and water. Another and a more common method is to dip them in a mixture of salt-water and lime, and then to spread them out for 4 or 5 days in the shade to dry. But the quantity of moisture imbibed during this process, appears to increase the liability to early decay and to the attacks of insects. The surest way of preserving the kernel

would be to export it in the shell; this is done in sending nutmegs to China; but it does not answer in Europe, on account of the heavy allowance for shells, which is one-third of the weight.

The general qualities of the nutmeg and mace are the same: their agreeable aromatic odour and pungent taste are well known, the peculiar flavour of the mace, however, being quite distinct from that of the nut. They contain, according to Bonastre, fat oil 31·6 per cent., volatile oil 6·0, starch 2·4, gum 1·2, free acid 0·8, lignine 54. Not more than 4·5 per cent. of volatile oil is usually obtained in the distillations at Apothecaries' Hall. The fixed oil, called *nutmeg butter* or *expressed oil of nutmeg*, is prepared in Holland: the nutmegs are beaten into a paste, which is enclosed in a bag, steamed and pressed between hot plates. It is imported in oblong cakes, wrapped in flag-leaves or leaves of the banana, and weighing about three quarters of a pound. It is of an orange or reddish brown colour, and of a fragrant odour. It is liable to much adulteration, and so also is the volatile oil, with which turpentine is frequently mixed. The article called *expressed oil of mace* is obtained from the nutmeg, and should bear its name. Nutmeg butter, according to Playfair, consists of three fatty substances, two of which are soluble in alcohol, and the third almost insoluble in that fluid: the third substance has been termed *Myristine*, and from this *myristic acid* is prepared.

Nutmegs are sometimes passed off as fresh, after the volatile oil has been abstracted from them. Such nutmegs are very light, and when pierced with a hot needle, do not give an oily coating to it. The best nutmegs are small, but heavy, weighing on an average 90 grains each. There is a large and inferior kind of nutmeg imported, longer and heavier than the above, weighing as much as 110 grains. This is the produce of another variety, and sometimes of a distinct species of nutmeg, and is said to be more liable to produce narcotic symptoms than the true nutmeg. Nutmegs and mace are decidedly stimulant, and in small quantities wholesome. When used in abundance they produce, by increasing the circulation, narcotic effects.

NUT-OIL. The kernels of walnuts and hazel nuts yield by expression an oil, which although at first greenish becomes clear and colourless,—hence it is esteemed by varnishers. It is also used as the vehicle for flake-white and other pigments where the clearness of the colour is required to be preserved. The warm climate of the South of Europe is favourable to the growth of the nuts which yield this oil.

NUX VOMICA. See STRYCHNIA.

OAK-BARK. See TANNING.

OATS. According to Vogel, oats consist of 66 per cent. meal, and 34 husk: dried oatmeal consists of

Starch	59·00
Bitter matter and sugar	8·25
Albuminous matter	4·30
Fatty oil	2·00
Gum	2·50
Husk, moisture and loss	23·95
	100·00

OBJECT-GLASS. See LIGHT.

OBLIQUE ARCH. See RAILWAY—and SKEW-BRIDGE.

OBSIDIAN, a volcanic glass containing 78 per cent. of silica. It has black and smoky tints, and was formerly used in Mexico for mirrors, knives and razors.

OCHRE, a native mixture of silica and alumina, coloured by oxide of iron, and sometimes containing a little calcareous matter and magnesia. The oxide of iron may occur in so large a proportion that the ochre becomes an ore of that metal. [See IRON, page 73.] Ochre is found in beds some feet thick, generally above the oolite, and covered by sandstone and quartzose sands more or less ferruginous, and accompanied by grey plastic clays of a yellowish or reddish colour. All these substances enter into the composition of the ochres. The ochry earths are ground under edge millstones and elutriated for use: the yellow ochres may be changed into red or reddish brown by calcination, whereby the iron is raised to a higher degree of oxidation. Native red ochre is also called *red chalk* and *reddle*. See BOLE.

ODOMETER, from ὁδὸς, a road, and μέτρον, a measure, an instrument for measuring the distances passed over in travelling. See PEDOMETER.

OILS and FATS. There are two great classes of oils, the *fat*, *unctuous* or *fixed*, and the *essential* or *volatile*. The latter have been noticed under ESSENTIAL OILS. Oils and fats may be liquid or solid, but they are easily fusible, and when brought in contact with paper they make a greasy mark, and render the paper translucent. The fixed oils occur both in vegetables and animals. In the former they occur chiefly in the cellular structure of the seeds, and are supposed by their oxidation or slow combustion to supply the heat necessary to germination. In animals they are deposited chiefly in the cellular membrane. The oils may be of very different consistence even in the same plant or animal; varying from a thin oil, such as almond or spermaceti oil, to solid lard or suet. The vegetable oils are usually obtained from the previously ground or bruised seed by pressure, in some cases assisted by heat. In animals the adipose cells are broken up on the application of heat by the liquefaction and expansion of the fat, which runs out or collects on the surface of the water in which it is boiled.

The constitution of fats is stated under CANDLE, to which we must refer. They are compounds of *stearic*, *margaric*, and *oleic* acids, with a base termed *glycerine*, and the *stearate*, the *margarate* and the *oleate* of glycerine are respectively termed *stearine*, *margarine*, and *elaine*. Fat depends for its consistence upon the proportions in which these substances occur: in the solid fats stearine or margarine prevails, and in the liquid oils elaine. The ultimate analysis of fats and oils reduces them all to carbon, hydrogen and oxygen. Some of them yield minute portions of nitrogen, the result of adhering impurities. The following table shows the relative proportions of the three elements in 100 parts of each of the oils named:—

	Carbon.	Hydrogen.	Oxygen.
Olive	77·21	13·36	9·43
Almond	77·40	11·48	10·82
Linseed	76·01	11·35	12·62
Nut	79·77	10·57	9·12
Castor	74·17	11·03	14·78
Whale	76·13	12·40	11·50
Spermaceti	78·91	10·97	10·12
Hog's lard	79·09	11·14	9·75
Suet	78·99	11·70	9·30
Butter	65·60	17·60	16·80

Fats and oils are colourless or of a slight yellow tint: they may be bleached by prolonged exposure to light: they are mostly without smell or taste, but the presence of certain volatile acids imparts peculiar odours to some of them; thus butter contains *butyric* and other *acids;* goat's fat *hircic acid;* whale oil *phocenic acid,* &c. The specific gravity of fats is less than that of water; but it varies greatly with their temperature. Thus common hog's lard at 60°, has a sp. gr. of 0·938: at 122° or in a fluid state, it is 0·892; at 152° it is 0·881, and at 200° it is 0·863.

	At 53°.	*At* 75°.	*At* 122°.	*At* 200°.
Nut oil	0·928	0·919		0·871
Almond oil	0·920			0·863
Linseed oil	0·939	0·930	0·921	0·881
Castor oil	0·970	0·957		0·908
Olive oil	0·919	0·911	0·893	0·862

The oils may be raised to a high temperature without decomposition; but at certain temperatures they deepen in colour, exhale vapour, and between 500° and 600° undergo decomposition. Hence they cannot be distilled in the ordinary way without being decomposed. The oils cannot properly be said to have any *boiling points,* for when they appear to be in a state of ebullition their glycerine is undergoing decomposition; the fatty acids are either volatilized or form new volatile products; carburetted hydrogen and carbonic acid are evolved, and carbon is left behind. During the distillation the oleic acid is partly converted into sebacic acid, and the stearic into margaric acid, while the decomposition of the glycerine produces an acrid vapour termed *acroleine.* These effects vary, however, with the nature of the oil. On passing the vapour of fats or oils slowly through a red-hot tube similar effects are produced together with a considerable quantity of hydrocarbons in a liquid, vaporous and gaseous form. Oil-gas is produced by a similar action as noticed under GAS-LIGHTING. What is called *oil of brick* or *philosopher's oil* is prepared by soaking bricks in oil and distilling the oil from them at a red heat in an iron alembic.

The recently expressed fixed oils are not much affected by the oxygen of the air: but by continued exposure to light and air, they absorb oxygen rapidly, and give out carbonic acid and hydrogen;—this action may even be so energetic as to produce ignition, especially where the oil exposes innumerable points to the action of the oxygen: as when it is absorbed by porous substances, cotton, tow and cloths used in lubricating machinery, and then thrown into a corner in a heap. There can be no doubt that steamboats, factories, and other places have been set on fire in this way. What are called *drying oils,* such as nut-oil, poppyseed oil, linseed oil and some others, seem to undergo this kind of oxidation: when exposed in thin layers to the air they dry into a kind of resinous varnish, a process which is greatly accelerated by the addition of a very small quantity of oxide of lead.

The *greasy oils,* on the contrary, do not dry, but become rancid by a similar exposure.

Chlorine, bromine, and iodine, form acids with the hydrogen of the fixed oils; on which account chlorine cannot in general be employed in bleaching the oils. Chlorine either in a free state or in the state of hypochlorous acid and chlorous acid, may, however, be used in bleaching some oils; but this method has not come into general use. Nitric acid, protonitrate of mercury, and in some cases sulphurous acid, convert many of the greasy oils into a concrete fatty matter termed *elaidine.* This action does not take place with the drying oils, and has therefore been proposed as a means for detecting the adulteration of olive oil with some of the cheaper oils from seeds, the presence of which retards the solidifying action; but the test is not very certain. Sulphuric acid abstracts the glycerine from oils and fats, forming with it *sulphoglyceric acid.* The use of sulphuric acid in the preparation of fats will be noticed further on: and for the action of alkalies upon fats we refer to SOAP. Under the influence of heat the oils dissolve small portions of sulphur, and phosphorus.

The purity of the fixed oils may be determined approximatively, and the admixture of cheaper oils detected, 1, by observing the peculiar odour of the oil when gently heated by a spirit lamp in a small porcelain or platinum capsule. The odour evolved will resemble that of the plant or animal from which it was obtained. In this way linseed oil, whale oil, train oil, or rape oil may be detected even when used to adulterate another oil. The test, however, is not always a safe one, for the odour of cold drawn oil may differ from the same oil expressed under the influence of heat. Olive oil has a different odour if grown at different places. 2. By mixing concentrated sulphuric acid with oil, (1 or 2 parts acid to 100 oil) the temperature rises and the mixture becomes coloured. If a plate of white glass be placed on a sheet of white paper, and 10 or 15 drops of oil be placed on the glass and a small drop of acid added, a colour will be produced which varies with the oil employed. With *rape oil* a greenish blue ring forms at a certain distance from the acid, while towards the centre light yellow-brown streaks may be observed. In *train oil,* from the whale or stock-fish, a peculiar motion begins at the centre and extends to the outside: a red colour appears and becomes more vivid: in 10 or 15 minutes the margin assumes a violet tinge which in 2 hours is uniform throughout. *Olive oil* instantly becomes pale yellow, and afterwards yellowish green. In *linseed oil* a beautiful dark brownish red web is formed, gradually changing into brownish black. *Tallow oil* or oleic acid becomes brown. "It seldom occurs that a better oil is used to adulterate an inferior one. Oil of almonds, olives, and codfish-oil, will, therefore, never be used for adulterating rape-oil, but pro-

bably train or perhaps linseed oil, and sometimes poppy oil. If we are led, therefore, by the odour to infer an adulteration,—for instance by train oil, which occurs the most frequently—it is only necessary to place from 10 to 15 drops of rape oil, the purity of which is undoubted, together with as much train oil, and an equal quantity of the oil whose purity is suspected, and to add to each of them a small drop of sulphuric acid. From the colour produced an inference may be drawn as to the purity of the oil, and by the difference of tinges from the vivid red of the train oil, and the bluish green of rape oil, the extent of adulteration may be detected." [1]

The purity of oils may also be tested by referring to their densities, which are said not to vary in an appreciable manner in the same oil produced in different years. In Saxony an acrometer or *oleometer* is used: it indicates the specific gravity of oils in such a way that pure rapeseed oil is indicated by 37° to 38°; hemp oil by 30° to 31°. There are various other tests: that by the capillarimeter indicates the quantity of oil which falls from a certain sized point under given circumstances. When oil of almonds or pure olive oil is shaken in a phial its surface remains even; but if mixed with oil of poppies it becomes covered with small air bubbles. When olive oil is surrounded with pounded ice it becomes completely solidified, which is not the case if adulterated with oil of poppies. Olive oil is sometimes adulterated with honey, which may be detected by shaking the oil with hot water, which dissolves the honey, and the oil separates when left at rest. The presence of fish oil in vegetable oils may be detected by passing through them chlorine, which turns them black.

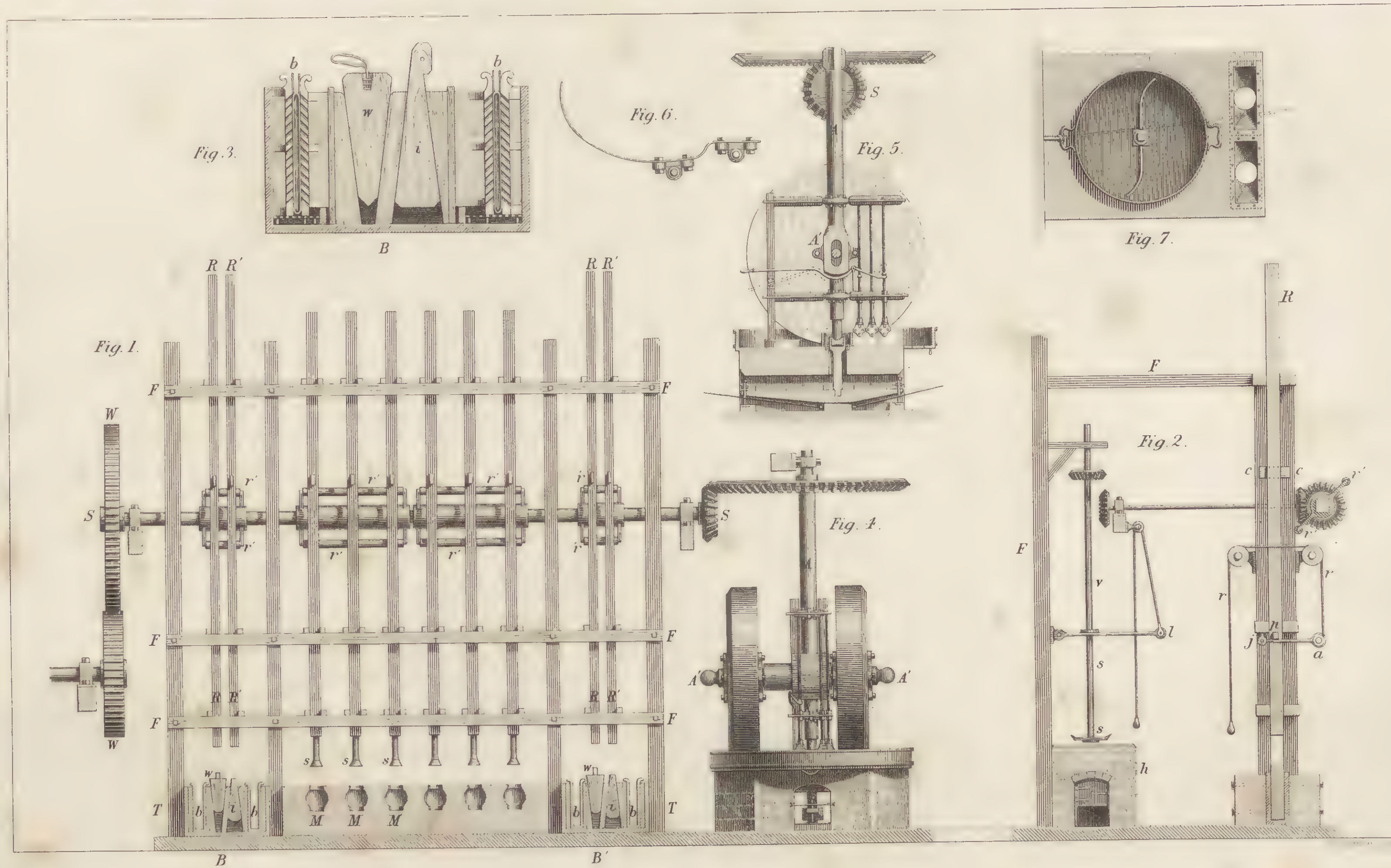
The following is a list of the principal unctuous oils of commerce:—

	Sp. Gr.
1. Linseed oil—*Linum usitatissimum et perenne.* Drying	0·9347
2. Nut oil—*Corylus avellana,* and *Juglans regia.* D.	0·9260
3. Poppy oil—*Papaver somniferum.* D.	0·9243
4. Hemp-seed oil—*Cannabis sativa.* D.	0·9276
5. Oil of sesamum—*Sesamum Orientale.* Greasy	
6. Olive oil—*Olea Europea.* G.	0·9176
7. Almond oil—*Amygdalus communis.* G.	0·9180
8. Oil of ben—*Guilandina mohringa.* G.	
9. Cucumber oil—*Cucurbita pepo et melapepo.* D.	0·9231
10. Beech oil—*Fagus sylvatica.* G.	0·9225
11. Oil of mustard—*Sinapis nigra et arvensis.* G.	0·9160
12. Oil of sunflower—*Helianthus annuus et perennis.* D.	0·9262
13. Rapeseed oil—*Brassica napus et campestris.* G.	0·9136
14. Castor oil—*Ricinus communis.* D.	0·9611
15. Tobacco-seed oil—*Nicotiana tabacum et rustica.* D.	0·9232
16. Plum-kernel oil—*Prunus domestica.* G.	0·9127
17. Grape-seed oil—*Vitis vinifera.* D.	0·9202
18. Butter of cacao—*Theobroma cacao.* G.	0·8920
19. Coco-nut oil—*Cocos nucifera.* G.	
20. Palm oil—*Cocos butyracea, vel avoira elais.* G.	0·968
21. Laurel oil—*Laurus nobilis.* G.	
22. Ground nut oil—*Arachis hypogœa.* G.	
23. Piney tallow—*Vateria Indica.* G	0·926
24. Oil of Julienne—*Hesperis matronalis.* D.	0·9281
25. Oil of Camelina—*Myagrum sativa.* D.	0·9252
26. Oil of weld-seed—*Reseda luteola.* D.	0·9358
27. Oil of garden-cresses—*Lepidium sativum.* D.	0·9240
28. Oil of deadly nightshade—*Atropa belladonna.* D.	0·9250
29. Cotton-seed oil—*Gossypium Barbadense.* D.	
30. Colza oil—*Brassica campestris oleifera.* G.	0·9136
31. Summer rapeseed oil—*Brassica præcox.* G.	0·9139
32. Oil of radish-seed—*Raphanus sativus oleifera.* G.	0·9187
33. Cherry-stone oil—*Prunus cerastus.* G.	0·9239
34. Apple-seed oil—*Pyrus malus.* G.	
35. Spindle-tree oil—*Euonymus Europæus.* G.	0·9380
36. Cornel-berry-tree oil—*Cornus sanguinea.* G.	
37. Oil of the roots of cyper-grass—*Cyperus esculenta.* G.	0·9180
38. Henbane-seed oil—*Hyosciamus niger.* G.	0·9130
39. Horse-chestnut oil—*Æsculus hippocastanum.* G.	0·927
40. Pine top oil—*Pinus abies.* D.	0·9285

(1) This plan is due to Mr. Heidenreich of Strasburg, and is quoted in full in Dr. Normandy's Commercial Hand-Book of Chemical Analysis, 1850, in which will be found a large amount of information respecting the methods of testing the purity of oils.

The proportion of oil contained in seeds is often very considerable: linseed contains 20 per cent. of oil; rape-seed from 35 to 40; castor oil seeds as much as 60 per cent. The oil is usually obtained by means of expression. An oil-mill is used for the purpose; but it is desirable first to pass such hard seed as lint or rape between iron rollers, in order to crack the shells. These rollers are of cast-iron, turned truly in a lathe, and their spindles run in brass bushes fixed in an iron frame bolted to the framework of the mill. These frames have mortises, in which the bushes for the rollers are placed and are adjusted by screws passing through the ends of the iron frames: this allows the rollers to be set at any distance apart, according to the size and hardness of the seed to be crushed. The rollers are sometimes of different sizes, so that different velocities may be given to their surfaces: this enables them to draw the seeds in, and to perform their work more quickly. One of the rollers has on its axis a small spur-wheel, which engages a cog-wheel on the main shaft of the mill. It conveys its motion by another pinion to the second roller. By giving to the roller pinions a dissimilar number of teeth, they may be made to revolve with different velocities, which answers the same purpose as making them of different sizes. Above the rollers is a hopper containing the seed, which runs out at an opening in the bottom into a trough or shoe, which is agitated by a piece of wood nailed to it resting on the cog-wheel: the shoe thus feeds the rollers with a small quantity of seed at a time, and prevents them from being choked up. A plate of iron attached to the frame on each side presses by its edge against the lower part of the rollers, and scrapes off any adhering seed. The crushed seed falls upon an inclined board, and collects in a heap, from which it is removed to feed the running stones. The arrangement of the rollers resembles that of the crushing-mill described under METALLURGY.

The seed broken by the rollers is passed under two vertical mill-stones or *runners,* revolving on a horizontal bed, where it is further bruised and prepared for compression. In some places the rollers are not used, but the seed is at once subjected to the action of the runners. Hard and smooth grains are, however, liable to slip away from beneath the running-stones, and thus require a much longer time to prepare them for the next process, that of compression. Rollers do their work rapidly, but they require great power to work them. When the seed is sufficiently bruised by either or both of these means, it is collected into hair bags and placed in what is called a *wedge-press* In olive-oil mills a screw-press may be used; but the



OIL-MILL.

hardness and smoothness of the grains of lint and rape, and the cavities formed by the broken shells which retain the oil, require the exertion of a stronger force. The hair bags containing the crushed seeds are placed between wedges of wood contained within a strong framing. The wedges are then driven down by a heavy ram or pestle worked by machinery until the pestle rebounds from them 3 times, when they are judged to be sufficiently tight. The oil thus obtained is of the *best quality*, and is kept distinct from that obtained by the after processes. The seeds come out of the bags in the form of flat cakes: these are broken up, and pounded in mortars with heavy stampers, which reduce the parenchyma of the seed to a fine meal, so that the oil can escape more freely when subjected to a second compression, which is now aided by heat. The pounded seed or meal is heated to the temperature of melting bees'-wax in a pan, and is kept in agitation by a spatula worked by machinery. The meal is again put into hair bags and compressed, and the resulting oil is considered to be the *best* of the *second* quality. Another compression produces oil of the *ordinary second quality*. During the heating of the meal a little water is sometimes added; but in Holland this practice is considered to be injurious. The cakes are still fat and soft, and are sold as food for cattle; but the Dutch break them down and stamp them again. The result is an impalpable paste, which is heated with a very little water, and kept for some time at the temperature of boiling water, with diligent stirring. It is then subjected to the greatest pressure that has yet been applied, and the result is an oil of the *lowest* quality. The cake is dry and hard like a board, and is used for manure. Some of the small millers in Holland purchase oil-cakes from France and Flanders for the purpose of preparing this inferior oil.

Our steel engraving represents an oil mill used for grinding and pressing linseed, rape seed, and other oily grains: W, Fig. 1, is a spur-wheel, which may be worked by water-power, steam, wind, or other convenient means. It engages the wheel W′, which is attached to, and gives motion to the horizontal tumbling shaft S S. This shaft carries round its circumference wipers for lifting the pestles, so arranged that each pestle may be raised twice during one revolution of the shaft. The wipers consist of a square socket, Fig. 2, fitted on the shaft with arms furnished with rollers *r r′* at their extremities, which produce less friction and wear than rubbing surfaces. The framework F F which supports the pestles consists of 4 strong uprights, with rails bolted firmly to them across, and to which small transverse pieces are attached for guiding the motion of the pestles. When not at work, the pestles are raised up by the levers *j a* engaging the projection *p*, Fig. 2, on the side of the lifter, so that the lifts are clear of the wipers: the levers turn upon a joint at *j*, and by releasing the rope *r*, the pestles are left free to work. The press boxes B B, Fig. 1, in which the grain is squeezed after it has left the running stones, Figs. 4 and 5, and the 6 mortars M M, Fig. 1, are contained in a strong block of stone or timber *t t*. The mortars are generally hollowed out of the block itself, and a board is placed on each side of the mortars inclined so as to form a trough which prevents the seed from being scattered by the fall of the pestles. The large press box B, Figs. 1 and 3, is also hollowed out of the block, or framed with sufficient strength to resist the enormous pressure of the wedges. This first box is used for pressing the grain as soon as it comes from the stones, and the second press-box B′ is used for squeezing the grain after it has been pounded by the pestles. The bags of seed *b b* are placed between iron plates, which are united at bottom after the manner of a book cover: the bag is shut up between them, and there are small holes in the bottom of the press, from which the oil oozes out into vessels placed to receive it: *w w* are the driving wedges, and *i i* the dischargers or inverted wedges for relieving the pressure. The rest of the press is filled up with blocks of wood, which rest firmly on the bottom to prevent them from being carried down by the wedges, and thin pieces of wood are placed between them and the wedges to make them slide more easily by each other. R R are the drivers which strike the wedges, and R′ R′ the stampers which strike the dischargers or relieving wedges. These rams are moved by wipers on the horizontal shaft, and their action will be better seen in Fig. 2, in which S is a section of the tumbling shaft, with the 2 wipers *rr′* attached to it; the roller at the end of each wiper engages the lift or projecting piece *c c* on the pestle R, and raises it to a certain height, when, being relieved by the revolution of the shaft, the pestle falls with its whole weight in the mortar: it is again raised by the next wiper, two blows being given for every revolution of the shaft. It will be seen that the action is precisely similar to that of the stamp-mill described under METALLURGY. The pan for heating the grain is shown at *h*, Fig. 2: it is a small circular copper pan, heated by a fire beneath: the spatula *s*, for stirring up the grain and preventing it from sticking to the bottom and sides and becoming overheated, is attached to the lower end of a vertical spindle *v*, the revolution of which causes the spatula to turn round in the grain. The spindle derives its motion from a horizontal shaft, furnished with a wheel at one extremity, by which it is moved by the main shaft, and a similar wheel, at the other extremity, allows it to engage the wheel at the top of the spindle by lowering the horizontal lever *l*. In its present position, the lever acting on a shoulder projecting from the spindle holds the latter out of gear. In front of the chauffer pan is a basket tapering downwards so as to form a narrow slit at the bottom. The hair bags are put into this basket and filled with the warmed grain, which is taken out of the chauffer with a ladle.

The plan now becoming common of heating the grain by means of steam is preferable to the above. A steam pan is shown in section, Fig. 1526. The grain is put into P, steam is admitted into the jacket by the pipe *s*, and the condensed water is let off by *w*. The form of stirrer is shown in Fig. 1527; and a

plan of the pan with the stirrer is given in the steel engraving, Fig. 7.

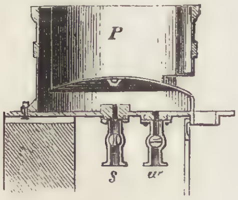


Fig. 1526.

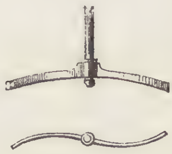


Fig. 1527.

The running stones are shown in the engraving, Figs. 4 and 5. They revolve in a strong frame-work attached to a vertical axis, which also slowly revolves by means of a large cog-wheel at the top, which engages a wheel upon the main shaft s. The stones have thus a double motion, one on their own axis, and the other, by which they are carried round upon the bed or lower millstone. A is the vertical axis, and A′ A′ the horizontal axis of the stones: this axis passes through the vertical axis, and has its bearing in the frame-work. The holes in the millstones are made rather wide, and those in the frame are vertically oval (see Fig. 5), in order to give greater freedom of motion, and to allow the stones to pass over any heaps of grain without straining. The bed-stone is supported on a strong foundation of masonry, and is surrounded by a raised border to retain the grain. In the centre is a block of wood carrying a brass bush, in which the vertical shaft turns. The grain is collected under the stones by means of rakes or sweeps attached to the framework, and revolving on the surface of the bed-stone, so that the grain which is spread and dispersed by the motion of the stones is collected into a ridge in the line of motion. The inner rake collects the grain under the outer runner, and the outer rake under the inner runner. The outer rake is also provided with a rag of cloth, which rubs against the raised border or hoop to collect any grains that might be attached to it. One of the runners is set about 2-thirds of its own thickness nearer the shaft than the other, so that the stones having different treads operate over a larger extent of surface. The inner rake gathers up the grain under the outer stone in a ridge shape, and the stone passes over it and flattens it, when the outer rake again gathers it up into a ridge. The outer rake consists of 2 parts, the outer of which presses close on the wooden hoop and pushes the seed obliquely inwards, while the inner part of the rake gathers up the grain which has spread towards the centre. The other rake has a joint near the middle of its length, by which the outer half of it can be raised from the nether stone, while the inner half continues to press upon it and scrape off the moist paste. Figs. 5 and 6 will show the form of these rakes, and the method of mounting them. When the seed is properly bruised, the man lets down the outer end of the rake, which gathers up the paste, and sweeps it obliquely outwards to the wooden rim, where it is brought to an open part of the hoop, and it falls out into troughs placed for its reception. These troughs are perforated at bottom, and a quantity of oil oozes out, and is conducted into a cistern apart: it is considered to be very pure, as it is obtained by the breaking of the shell and not by expression, which may be supposed to introduce mucilage and other matters into the oil.

In the oil cisterns the parenchymous part of the seed gradually subsides, and the liquor in the various divisions or cisterns consists of oil of different degrees of purity. The pumps which raise it from the cisterns are in pairs: one pump lifts it up from the very bottom, and the other from half the depth. The last only is barrelled for the market: the other half is put into a deep and narrow cistern, where the dregs again subside, and more clear oil is obtained. A press will crush 7 cwt. of seed per day in the first operation, when the grain comes immediately from the rollers; but only 2 or 2½ cwt. per day in the second pressing, which requires a much longer time. A quarter of linseed produces on an average from 15 to 18 gals. of oil.

The action of sulphuric acid upon fatty substances has been already referred to as laying the foundation of a considerable branch of industry, by which the most fœtid and impure fats and oils can be completely purified, and converted into pure stearine adapted to the manufacture of candles.[1] Sulphuric acid exerts upon fats an action somewhat similar to that of the alkalies; with which the fatty acids unite, and the glycerine is set free: but in the case of sulphuric acid there is this difference; the acid combines at first with the whole of the fatty substance, and the glycerine is afterwards isolated under the action of water in the form of sulphoglyceric acid: double acids are then formed with each of the other fatty acids, forming *sulpholeic*, *sulphomargaric*, and *sulphostearic* acids, the first of which is soluble in cold water, while the two others are decomposed by it: all three are decomposed by boiling water, which forms a solution with the sulphuric acid and the glycerine, and leaves the fatty acids floating on the surface.

The fatty substances employed in what the French chemists term the *sulphuric saponification*, are the most inferior greases and refuse that are sent into the market. In France the sources of supply are, 1, the soapy waters obtained by washing woollen cloth after the process of fulling; 2, bone fat, obtained by boiling down bones; 3, the miscellaneous collection which in England is known as *kitchen-stuff;* 4, the refuse matters of olive and other oil-mills; 5, the scrapings of the cat-gut manufacturer; 6, refuse of cod-liver oil, whale oil, &c.; 7, residue of soap works, &c. &c.

In the treatment of the soapy waters, which contain a mixture of olive oil or oleic acid and soap, sulphuric acid is added, which, combining with the alkali

(1) An interesting paper on the Stearic Candle Manufacture was read before the Society of Arts on the 5th Feb. 1852, by G. F Wilson, Esq., Managing Director of Price's Patent Candle Company. This paper has been printed for the use of the Members. The Jury Report, Class XXIX., also contains a historical notice of this important manufacture, with short accounts of the lime process and the acid saponification.

present, causes the fatty matters to separate and rise to the surface. The fat is removed by means of flat colanders to a water-bath, where it is fused at a very moderate heat: the fluid oil is decanted off, and the solid deposit is put into woollen bags and subjected to pressure under the influence of heat; by which the fluid acid is separated from the solid.

Should the fatty substance be contaminated with dirt, clay, wool, &c., it is put into bags, and cold-pressed in order to separate water. It is next pressed in a cast-iron box heated by steam, by which means the fluid oil is separated. It is next fused in a water bath: the purer fluid portion is decanted, the solid portion is subjected to the chemical processes about to be described, while the muddy residue is made to give up its remaining fat by the action of boiling water and another pressure, and what is left is employed as manure.

The first washing of the fatty substances by means of sulphuric acid is conducted in large wooden tubs lined with lead, and heated by steam discharged into them by a perforated pipe. The agitation is kept up for from 15 to 30 minutes, and after reposing for a similar length of time, the water is drawn off by a pipe at the bottom into a vessel similar to Fig. 1529, in which the fatty matters carried off by the water are retained. The fat which has been thus washed is put into a vessel heated by means of a steam-jacket, and the water is driven off by evaporation. The fat is then ready to be treated with strong sulphuric acid, an operation which is carried on in a boiler of copper or iron B, Fig. 1528, furnished with a steam-jacket. Above the boiler is a chamber H for collecting the fumes of sulphurous acid, fatty acids, acroleine, &c.: these are drawn off by means of a pipe V proceeding from the chamber to the ash-pit of the furnace fire, where they are got rid of by being passed through the fire, thus preventing a prolific source of nuisance, not only to the factory, but also to the neighbourhood.

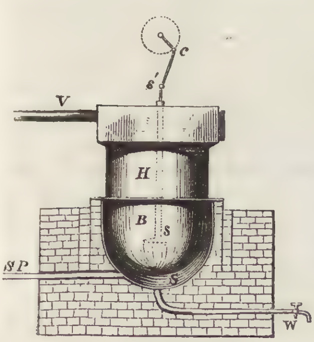


Fig. 1528.

The fatty matters are kept in a constant state of agitation with the sulphuric acid by means of a mechanical stirrer *s s′* moved by a crank *c* which acts similar to the beater of such a churn as is represented in Fig. 389, article BUTTER. This prevents the heavy matters from subsiding. The proportion of sulphuric acid employed varies with the kind of fat: mixed fats require from 10 to 13 parts of concentrated acid for every 100 parts of fat: palm oil, 8 or 9 per cent. of acid, while certain solid fats take from 12 to 16 per cent. These proportions are ascertained beforehand by experiment. The temperature of the mixture is maintained at 230° to 240° Fahr., and the operation lasts from 12 to 18 hours. Specimens of the liquid are taken out from time to time and poured into an evaporating dish: the kind of consistence acquired in cooling, and the disappearance of the violet tint, shows how the operation is going on, and whether it is near completion. When the fat is properly converted it is left to cool for 2 or 3 hours, after which the liquid is drawn off

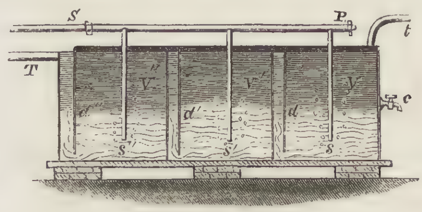


Fig. 1529

by a syphon *t*, Fig. 1529, into a cistern V, which contains one-third of water: steam is now injected into it from the steam-pipe S P by means of the perforated branch *s*. The water, thus raised to the temperature of 212°, effects the decomposition of the sulpho-fatty acids: the fatty acids float on the surface, and they are washed by means of boiling water conducted by the pipe *t*, by which they were conveyed into the vat. The water, holding in solution sulphoglyceric acid, and several foreign matters, passes under the diaphragm *d* of the first vat, and flows into the second vat V′: steam is injected into it by means of the pipe *s′*, furnished with a stop-cock for regulating the supply: the temperature is thus raised to 212°: the larger portion of the acids which had been dragged over by the water rises to the surface, while the watery solution, passing under the diaphragm *d′*, enters the third vat V″, where similar effects are produced. The aqueous portion passes under the diaphragm *d″*, and it is directed by an overflow-pipe T into a series of 3 or 4 other vats similarly arranged, but formed of masonry or of compact bricks cemented by bituminous mastic.

During the acid saponification and the washings, the fusing point becomes raised, as for example:—

	Fuses at	*After the action of the acid at*	*After washing. at 212°, at*
Bone fat and stuff ...	75°	97°	100·4°
Palm oil	86	100·4	111

The fatty acids having been purified by washing in the first vat V, are drawn off by a stop-cock *c* placed above the level of the water, into a vat which feeds the distillatory apparatus. The fatty matters floating in the vats V′ V″, are skimmed off, and transferred to the first vat V, where they are washed with the products of a second acid saponification. After each saponification, there remains at the bottom of the boiler a black bituminous substance, forming from 4 to 10 per cent. of the stuff originally employed. This substance after having been washed with boiling water, might be used in the manufacture of gas for the purposes of illumination. The vat in which the purified fatty matter is collected, is warmed by a jacket, in which circulates the water from the condensed steam on its way to the boiler cistern. This keeps the vat at a temperature of from 100° to

120°, at which moderate heat some foreign matters and water mechanically mixed, become deposited. The fatty matter is decanted into a flat boiler F, Fig. 1530, which is furnished with a dome-shaped cover, so that the water which condenses on its under surface may trickle down into a gutter, which forms a water lute to the vessel, and from this gutter it escapes by an overflow-pipe. In this boiler the fat gets rid of water, and it is raised to the required temperature by the waste heat of the furnace below, escaping into the flues. This furnace is used for heating the tubes *s s*, which are filled with steam by the cock *s b*, which communicates with a boiler. The steam in the tubes *s s*, is raised to the temperature of about 570°, and on opening the stop-cock *c*, it is admitted into the boiler B by the perforated tube and rose-head *r*. The boiler B is of copper, with a domed cover D, in which is a man-hole. Heat is applied to the boiler by means of a sand-pot *s s*, and the whole is surmounted by a hollow cover C,

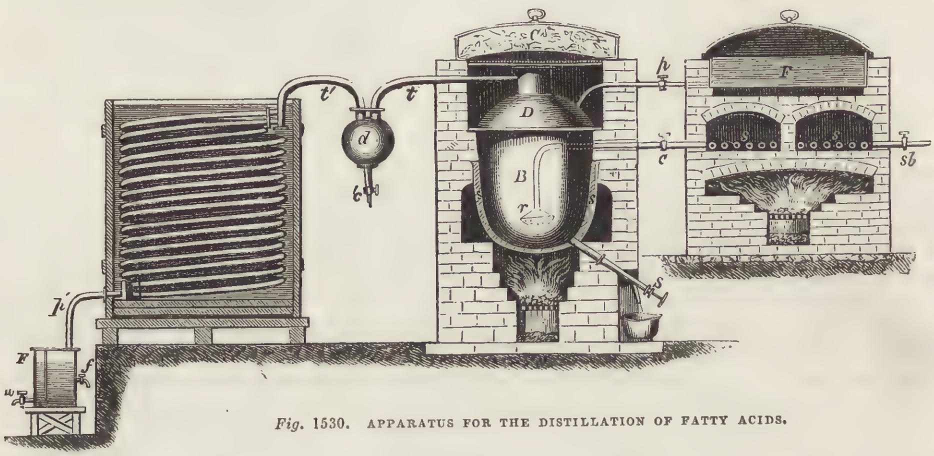


Fig. 1530. APPARATUS FOR THE DISTILLATION OF FATTY ACIDS.

containing hot cinders, which keep up the temperature. The liquid fat is introduced into B by means of the pipe *p*, the flow being regulated by the stop-cock. When the liquid fat has reached 480°, the high-pressure steam is admitted, a thermometer let into the pipe near *c*, indicating its temperature, which is kept at from 480° to 580°. At such a heat, and under the influence of the steam, the last portions of the neutral fatty matters are transformed into fatty acids and glycerine, the former of which are carried away in the current of steam along the pipe *t*, into the vessel *d*, and from thence by the tube *t'* into the double worm. The vessel *d* allows of the separation of the first portions of the distillation, which contain sulphuric acid, acroleine, &c. The fatty and aqueous vapours are condensed in the worm, and the liquids flow by the tube *p'* into a Florentine receiver F. The lighter fatty acids remain in the first division, and can be drawn off by the stop-cock *f*, while the aqueous portion passing below the diaphragm can be discharged by *w*.

The fatty acids which are successively volatilized in B, vary in composition with the time occupied from the commencement of the operation, and the nature of the crude material, so that the condensed products have different fusing points, as for example:—

	Green fats and bone fats	Palm oil.
1st product	104°	130°
2d ,,	106	125·5
3d ,,	106	118·5
4th ,,	108	115
5th ,,	111	111
6th ,,	113	106
7th ,,	106	102·5

In the course of 12 or 15 hours, from 18 to 22 cwt. of fat may be distilled in the alembic B, which is about 5 feet in diameter, and 6 feet high. There remains in the boiler a brown fluid residue, which is removed by means of a syringe S, which passes up into the boiler. This fluid acquires, on cooling, the consistence of asphaltum or bitumen: it amounts to 6 or 7 per cent. of the matter produced from green fats and bone fats, and 4 or 5 per cent. of the weight of palm oil. No use has hitherto been found for this substance, but it might probably be employed in the manufacture of blacking, of black sealing-wax, of a black varnish for leather, or even of a common kind of soap. Indeed there are many waste products which might be converted into soaps with great advantage to the manufacturer, and still greater to the consumer, did not the unwise regulations of our excise interfere.

By a modification of the apparatus just described, the operation is made continuous. It consists of a cylinder C, Fig. 1531, surrounded by a vessel L, containing molten lead, which communicates the amount of heat required. A man-hole above C, usually kept closed, gives access to the cylinder for repairs, &c. The acidified fat, washed and dried, as already explained, is poured into the cylinder in a small stream by means of the funnel *f*, the stem of a float within the cylinder cutting off the supply when it has reached a certain height. The mixture of fatty acids in the cylinder being kept at a temperature approaching 600° by means of the lead bath, steam is injected into the cylinder. The steam is conveyed from the boiler by means of the tube *s p*. It first passes into the vessel

w, where any particles of water, which may be entangled with it, are either deposited or vaporized.

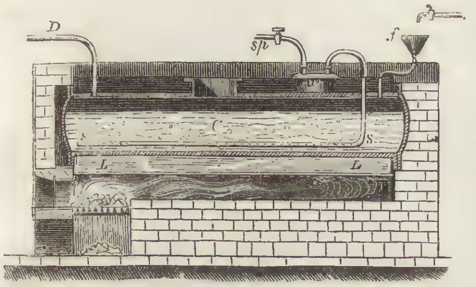


Fig. 1531.

The steam then passes into the cylinder by the tube *s s*, the horizontal part of which, placed near the bottom of the apparatus, is pierced with a multitude of holes, and thus the steam flows up through the mixture of fatty acids, the vapours of which are carried by the steam along the pipe D into the refrigerator. At the end of every 3 or 4 days, the black carbonaceous accumulation in the cylinder must be drawn off, as in the former case.

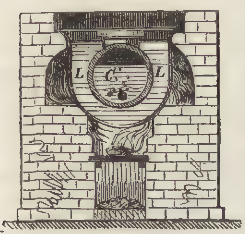


Fig. 1532.

The fatty products of the distillation are received into large crystallizing pans of cast-iron, lined with enamel, and they are further purified by pressure, either at ordinary temperatures, or under the influence of heat. In the distillation of palm-oil, the last products may be treated in a similar manner; but the first portions, which fuse at from 115° to 130°, can be moulded into candles without further preparation. The white cakes of the second hot-pressing of the distilled products of mixed fats, are melted in vats heated within by means of a coil of pipe, through which steam circulates. Here they are clarified by means of hot water containing a little oxalic or sulphuric acid, and this terminates the process.

The percentage of solid fatty acids obtained from refuse and other fats and oils by the above processes, varies considerably with the nature and source of the material: for while palm oil will yield from 70 to 80 per cent. of solid available matter, the waste oleic acid of the stearine factories will only give from 25 to 30 per cent. The fat produced by boiling garbage, &c., 60 to 66 per cent., waste olive oil 55 to 66, and so on.

The hydrostatic press is used for pressing out the oleic from the solid acids, as explained in our article CANDLE. In hot-pressing, the distribution of the heat uniformly has been a difficulty. The presses have been arranged both vertically and horizontally, the latter position being more convenient. The bags containing the fatty matter are placed between cast-iron plates, having a serpentine hollow or channel through the middle of their thickness, as shown in Fig. 1533, for the passage of steam, and thus they can be raised to the desired temperature; the steam is supplied to them by tubes furnished with articulated joints, so as to follow the motion of the press. This arrangement will be better understood by referring to Figs. 1535, 1536, in which S T is the steam-tube communicating with the boiler; on opening the cock at *c*, steam enters all the tubes *s t s' j*, and passes down the channels in the iron plates *i p*, shown more distinctly in Fig. 1534. Joints at *s j* allow of the motion of the boxes, and a stuffing at *t*, where the thinner tube enters the thicker one, allows the tube *s t* to play steam-tight in *t s'*. Fig. 1534 represents two plates with the horse-hair or matting-bag between them containing the fat, which has already been cold-pressed: R, Fig. 1535, is the ram of the hydrostatic press, and *w* the tube which conveys water from the force-pump; V is a safety-valve. The fluid oil expressed from the solid acids is received into a channel *g*, which conveys it to a vat *v*. It may be used as a common oil for lamps, or for the preparation of soaps.

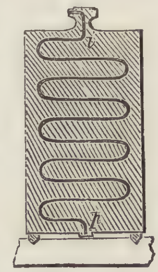


Fig. 1533.

Fig. 1534.

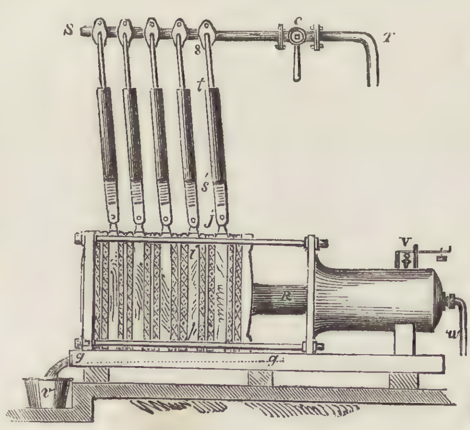


Fig. 1535.

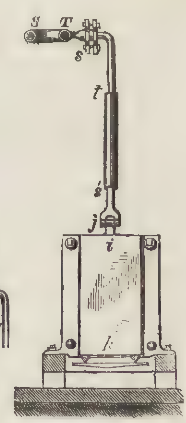


Fig. 1536.

We conclude this notice of the sulphuric saponification, with an abstract of the process as conducted at the works of Price's Patent Candle Company, and described in the Jury Report, Class XXIX. See also CANDLE.

About 20 tons of fat, say palm oil, are fused by a steam-jet in a lead-lined vat. The fluid mass having settled, is pumped up into the acidifying vessel, and

heated to 350° by a steam-jet. Concentrated sulphuric acid in the proportion of 6 lbs. for 112 lbs. of oil is used, and under the influence of the acid and the steam the oil is decomposed, and much blackened. The fat is drawn off into the washing tub, and boiled up with water by means of a steam-jet. After one or two washings the blackened fat is pumped up to the supply tank, which commands the stills. These are of copper, heated by an open grate, each still capable of holding 5 tons of fat. The temperature is raised to 560°, and steam is passed through the mass. The steam and fatty acids distil over into a series of vertical pipes of the temperature of 212°, where the fats only condense while the steam passes to a second refrigerator cooled by a current of water. Here it is condensed together with the minute portion of fat carried over, which floats on the surface, and is recovered while the water flows off at bottom. After the distillation has been continued for some time, the residue in the still is transferred to another still, formed of iron pipes set in a furnace, and there submitted to a higher degree of heat, and to the action of more highly heated steam. An additional quantity of fatty acids is thus obtained. The residue left is a sort of pitch, and may be used as such. The fatty acids as they run from the still are used without pressing in the manufacture of *Composite candles:* they are self snuffing, but more fusible and soft than the pressed stearic acid candles. A better sort of candle is made from the pressed acid, 50 hydraulic presses being used for the purpose. In cold pressing, the fats are spread on woven mats, and pressed between iron plates: the oleic or metoleic acid which runs out is sent to Germany to be made into soap. The fat acids are next hot-pressed in hydraulic presses confined in a chamber heated by steam. The pressed cakes are melted in contact with a little dilute sulphuric acid, and run into blocks which are used for making candles. [See CANDLE.] Pressed coco-nut oil is largely employed to mix with the pressed acids of palm oil for the best composite candles.[1]

OIL COLOURS. See PAINTING.

OIL GAS. See GAS-LIGHTING.

OLEIC ACID. See CANDLE—OILS and FATS.

OLIBANUM. A fragrant gum-resin which constituted the frankincense of the ancients, and which also possesses stimulant, astringent, and diaphoretic properties. The tree which produces it is the *Boswellia serrata*, which grows freely among the mountains of Central India, as well as among those of the Coromandel coast. It forms one of a group of trees exclusively natives of tropical India, Africa, and America, and yielding myrrh and frankincense with an abundance of fragrant resinous juice.

(1) Among the authorities referred to in the preparation of this article we may mention Dumas, Chimie Appliquée, tome v.; Payen, Chimie Industrielle; the volume on Arts and Manufactures in the Encyclopædia Metropolitana; and two volumes in the Encyclopédie Roret, entitled, "Manuel du Fabricant et de l'Epurateur d'Huiles," par M. Julia de Fontenelle, 1836; and "Manuel complet de la Fabrication des Acides Gras concrets et de celle des Bougies Steariques," &c. Par M. F. Malepyre. Paris, 1849.

Olibanum is imported from India in round, oblong, or ovate tears, of a pale yellow colour, partially opaque, and having a balsamic odour. According to Johnston, lumps of this substance, which only appear to differ slightly in colour, behave differently when treated with alcohol; some become quite transparent, others white and opaque, from a powdery coating left on the surface. The latter contain an acid resin $= C_{40}H_{32}O_6$, constituting the larger portion of the olibanum of commerce, and associated with a variable quantity of volatile oil. The clearer and yellower pieces give less gum than the others, and contain a resin represented by $C_{40}H_{32}O_4$ and resembling colophony. It is uncertain whether the substance known as Arabian frankincense is the produce of an Arabian tree of the genus above described. The affinity in vegetation between parts of India, Persia, and Arabia, would lead to the supposition that it is so, but on the other hand, many fragrant substances once supposed to be the produce of Arabia, are now found to have been first obtained from India or Africa, and then re-exported.

OLIVE OIL. Vegetable oils are in most cases extracted from the seeds of plants, but in the case of the olive, the best oil is contained in the pulpy part of the fruit, and this is carefully extracted before the seeds are subjected to pressure. The olive is a tree which grows luxuriantly in Italy, whence our chief supply of the oil is obtained; but it is not indigenous to that country, having been transmitted thither from its home in the east. Asia, the birthplace of civilization, was likewise the birthplace of the olive; and in the western world the tree followed the progress of peace, of which it is considered the symbol. The olives in Syria and the Holy Land are very numerous and of great age, springing up without culture in wild luxuriance. The olive-groves of Greece are likewise famed, and some of the Greek islands export large quantities of the oil. Olive oil is also to be obtained on the African coast, and in the south of France and Spain.

The olive-tree is not very much unlike the English willow, and is frequently pollarded in a similar manner. The scenery in that part of Italy which may be called "the heel of the boot," is rendered monotonous by the immense olive-groves which cover the country. Throughout the whole of the two provinces Bari and Lecce, or La Terra d' Otranto, scarcely anything else is cultivated. The most celebrated port of these provinces is Gallipoli, which gives its name to the oil brought from an extensive district. Great part of the merit of Gallipoli oil arises from the facilities which that town possesses for keeping it pure and fresh after it is brought in from the country. These will be noticed presently, but we must first describe the very simple means employed to procure the oil.

Olive-trees begin to bear at two years old, but are not in full bearing until after five or six years, when they become a sure source of wealth to their owners. They are of extreme longevity, and will bear luxuriant crops when the trunk is quite hollow. A tree of this

description, whose empty shell scarcely supported it against the mountain storms, is stated to have produced in one year 240 English quarts of oil. Some years ago there was an olive-tree near Nice in a decaying state, which had been the wonder of that part of the country on account of its enormous size and great age. The lowest extremity of the trunk measured 38 feet, and one of the main branches 6½ feet in circumference. As far back as 1516 this tree was distinctly recorded as the oldest in the neighbourhood. In former years it has borne upwards of three hundredweight of oil in one season, and so late as 1818 it produced two hundredweight. A celebrated olive-tree at Pescio was said to be 700 years old. These, however, are exceptional cases, and it appears probable that the majority of trees do not continue productive much above a century, unless great attention is bestowed upon them.

The ingathering of the olives is performed in different ways. Some cultivators allow the fruit to attain complete ripeness and to drop from the trees. Others consider that the fully ripe fruit produces too fat an oil, and one which is liable to become rancid; they therefore gather it a little before it is ready to drop. Others again prefer gathering the fruit some little time before it is ripe, but the oil thus obtained is liable to be sharp or bitter. The fruit is sometimes beaten off with poles, a very injurious plan for the trees. The olives likewise are bruised, and unless used directly, the oil obtained from them has a bad flavour. The more tedious process of hand-gathering is therefore to be greatly preferred. In order to obtain the finest description of oil, the ripe fruit is conveyed at once to the mill, or if unripe, it is allowed to lie for 24 or 48 hours in a dry place until it begins to wrinkle. For inferior oils or for soap, the olives are heaped up in storehouses, sometimes for months together, and lose much oil from fermentation, while that which remains is greatly deteriorated in flavour. With proper precautions, however, such as frequent turning of the heaps, leaving spaces for the air to circulate, and keeping the several gatherings distinct, much of this loss may be avoided.

The crushing of the olives is effected in a mill of the simplest construction, consisting sometimes of a single mill-stone, turning in a circular bed: at others, of two mill-stones, placed far enough apart not to crush the seeds. The workmen remove the pulp when sufficiently crushed, and place it in bags or sacks, which are heaped up on the platform of a press. This is also of a very rude description, and gives but a slow and feeble pressure. The oil which first exudes from the olives (supposing them to be of good quality) is a fine pure oil, much sought after for the supply of the table. It is known in commerce as *virgin salad oil*. After this is all extracted, there yet remains a considerable quantity so mixed with vegetable albumen that it cannot flow out. The bags of pulp are therefore lifted up, and between each is poured a certain quantity of boiling water. This causes the pulp to swell by the absorption of the water: the albumen coagulates, and the more fluid oil flows freely. Still a certain quantity of oil remains among the refuse, and this is subjected to further treatment in separate workshops, the resulting oil being only fit for soap-making. The imperfection of the former processes alone renders these latter ones necessary, so that a large amount of time and labour is thus unnecessarily expended.

As soon as the first run of fine oil is obtained from the olives, it is conveyed in jars or skins to a reservoir, and on the nature of this reservoir much of its after value depends. The town and port of Gallipoli owe much of their celebrity to the circumstance of the former being built on a rocky island, easily excavated into caverns and cisterns where the oil soon clarifies, and can be long preserved without becoming rancid. A Gallipolitan oil-house is described as being the ground-floor of a dwelling-house, in the stone basement of which 4, 6, or more circular holes are seen, about 2 feet in diameter, resembling the mouths of wells. These are the openings to separate cisterns reserved for different qualities of oil. The oil brought in a turbid state to these excellent reservoirs soon becomes bright and yellow, and in some cases may be kept for a period of 7 years. It is carried thither in sheep or goat-skins, generally on the backs of mules, and when it is to be shipped, it is drawn off from the cisterns into skins, and carried on men's shoulders to a house on the sea-shore, where there is a large open basin capable of containing a given quantity, and of measuring the liquid, and into that the porters empty their skins as they arrive. A tube leads from the basin to a large cock on the outside of the house. Under this cock are placed casks of various sizes, and the oil is thus conveniently drawn off into them. Coopers are at hand to close the casks securely, after which they are rolled down to the beach, and being fastened, several together, by ropes, they are attached to a boat, which tows them through the water to the ship's side. The number of persons employed in all these operations is very great, and their cheerfulness, frequently exhibited by singing in concert, gives a very lively effect to the whole scene. The produce of a full crop of oil, in the province of which Gallipoli forms the chief outlet, was, in 1843, nearly 22,000 tuns.

Fine *Spanish soap*, known in England as *Castile soap*, is made of olive oil mixed with alkalies. A similar manufacture is carried on at Marseilles, which has a large export trade in soap.

Olive oil is largely used in Greece, Italy, Spain, and France, as an article of food, and in medicine, and the arts. It is extensively used in England, especially in the woollen manufacture. The fine oil, called *Florence oil*, used for culinary purposes, is brought from Leghorn in chests containing 30 bottles, or 4 English gallons.

Oil of olives varies in colour from greenish to pale yellow. A little above the freezing point of water it begins to deposit some white granules of stearine. At 22°, it deposits 28 per cent. of its weight of stearine.

OMBROMETER. See Rain-gauge.

ONYX. See AGATE.

OOLITE. A species of limestone rock characteristic of one of the great systems of secondary strata. The stone is composed of globules or grains, clustered together often without any apparent cement or base. The resemblance of these grains to the ova or roe of fishes, originated the English term *oolite* (ὠὸν, an egg), and the German *Rogenstein*, or roestone. The globules vary in size, from that of small pin heads to peas. In some cases they occur in concentric layers, in others they are compact or radiated. One of the purest examples of oolite is the fine yellow freestone of Ketton in Northamptonshire. It is composed of round grains of concretionary structure, adherent by their contiguous surfaces, forming an easily worked durable stone. In the Bath freestone, the grains are often hollow, and are connected by interposed calcareous matter. The Portland stone is similar, but contains disseminated or aggregated silex. In the Lincolnshire freestone the round grains are compacted in a basis of crystallized carbonate of lime. The oolitic series includes all the strata between the iron sand above, and the red marl below. In the midland and eastern parts of England, it yields admirable building materials. It is divided into three systems:—the *upper*, the *middle*, and the *lower oolite*. The first includes the argillo-calcareous Purbeck strata, which separate the iron and oolitic series; the oolitic strata of Portland, Tisbury, and Aylesbury; the calcareous sand and concretions as at Shotover and Thame, and the argillo-calcareous formation of Kimmeridge. To the second belong the oolitic strata, associated with the coral rag; calcareous sand and grit; great Oxford clay, which attains a thickness of 500 feet, between the oolites of this and the following system. The lower oolite contains numerous oolitic strata, and is, in some places, subdivided by thin argillaceous beds. It includes the corn-brash (the uppermost bed); then the forest marble, schistose oolite, and sand of Stonesfield, and Hinton, great oolite, and inferior oolite: calcareo-siliceous sand passing into the inferior oolite: great argillo-calcareous formation of lias and lias marl, which forms the base of the whole series of the lower members of the oolitic system. The great oolite is the most important, both in thickness and practical utility. It is separated from the inferior oolite by a series of marly beds, which contain among them that particular kind of clay known as *Fuller's earth*, and also a thin bed of calcareous flagstone known as the *Stonesfield slate*. The inferior oolite includes a thickness of about 40 or 50 feet of freestone. On the continent of Europe the oolitic system is known as *Jura kalk* and *Calcaire Jurassique*, from the conspicuous development of the strata in the Jura mountains.

OPAL. This beautiful mineral consists of silica with from 5 to 12 per cent. of water. It generally contains a little oxide of iron, and a small quantity of the alkaline earths. Eleven varieties have been described. 1. *Precious*, or *noble opal*, is white, bluish or yellowish white, and exhibits a beautiful variety or play of colours, as blue, green, yellow, or red. The fracture is conchoidal, with a vitreous or resinous lustre. It scratches glass, but is easily broken on account of the numerous fissures by which it is traversed, and which probably give rise to the splendid play of colours. Opals are cut with rounded faces. The sp. gr. of precious opal is 2·06 to 2·09. 2. *Fire opal. Girasol*, in which the internal reflection is bright red. It occurs with the precious opal in Hungary, and has also been found in Cornwall. 3. *Common opal*, or *semiopal*, has the hardness of opal, and is easily scratched by glass, which distinguishes it from some siliceous stones often called semiopal. It has sometimes a milky opalescence, but does not reflect a play of colours. 4. *Hydrophane* is usually opaque, but by immersion in water, it exhibits the iridescent colours of the precious opal. 5. *Cacholong*, first brought from the river Cach in Bucharia, resembles chalcedony, but contains water and a little alumina. 6. *Hyalite, Müller's glass, Fiorite*, a glassy transparent variety, resembling transparent gum-arabic. It occurs in small concretions, stalactitic, and stalagmitic. 7. *Menilite*, found in kidney-shaped masses at Mount Menil, near Paris, is a brown opaque variety, not unfrequently slaty. 8. *Wood opal* is wood petrified with a hydrated silica: it is of a grey, brown, or black colour, and has the structure of wood. 9. *Opal-jasper* resembles jasper, but contains iron, and is not so hard. 10. *Tabasheer*, a siliceous aggregation found in the joints of the bamboo. 11. *Siliceous-sinter*, deposited from hot springs, and near volcanoes, has sometimes an opaline character.

OPIUM, an inspissated juice (ὀπος, the *juice*), from the capsule of the white poppy, *Papaver somniferum*. It grows wild in some parts of England, and is cultivated for its opium in Hindostan, Persia, Asia Minor, and Egypt. In Europe the poppy is cultivated for the capsules, either as medicinal agents, or for the oil obtained from the seeds. The London market is chiefly supplied with poppy-heads from Mitcham in Surrey. The heads are usually collected when quite ripe, but they would be more active as medicinal agents if gathered while green. They vary in size from that of a hen's egg to that of the fist. Their texture is papyraceous, and on the top is a star-like stigma. Their colour is yellowish, or yellowish brown, and if collected before they are ripe they have a bitterish taste. When fresh they have a slightly opiate odour, which disappears in drying.

The method of extracting opium is to a certain extent similar in all countries: it consists in making incisions in the half-ripe capsules, and collecting the juice which exudes. The process, as followed in Asia Minor, is as follows:—"A few days after the flower has fallen, men and women repair to the fields, and cut the head of the poppy horizontally, taking care that the incisions do not penetrate the internal cavity of the shell. A white substance immediately flows out and collects in tears on the edges of the cuts. In this state the field is left for 24 hours, and on the following day the opium is collected by large blunt knives. Each head furnishes opium once only, and that to an extent of a few grains. The first sophisti-

cation which it receives is that practised by the peasants who collect it, and who lightly scrape the epidermis from the shell to augment the weight. This operation adds about $\frac{1}{12}$th of foreign matters. Thus collected, opium has the form of a glutinous and granular jelly. It is deposited in small earthern vessels, and beat up with saliva. When asked why water was not employed in the place of saliva, the answer was that water caused it to spoil. It is afterwards enveloped in dry leaves, and in this state it is sold. The seeds of those poppies which have yielded opium are equally good for sowing the following year."[1]

Several varieties of opium are known in commerce. The principal kind is that from Smyrna, known as *Turkey* or *Levant* opium. "It occurs in irregular rounded or flattened masses of various sizes, rarely exceeding 2 lbs. in weight, enveloped in leaves, and usually surrounded with the reddish capsules of some species of *Rumex*. Some of the flat cakes are without these capsules, and somewhat resemble Constantinople opium. When first imported the masses are soft and of a reddish-brown colour; but by keeping they become hard and blackish. Its lustre is waxy; its odour is strong and unpleasant; its taste is bitter, acrid, nauseous, and persistent. M. Guibourt regards the masses as being made up of agglutinated tears, and on this account as being the purest met with. It is, however, frequently met with largely adulterated. In one sample, weighing 10 ounces, I obtained 10 drachms of stone and gravel. Notwithstanding occasional frauds of this kind, Smyrna opium forms the best commercial opium." (*Pereira.*) It yields more morphia and meconic acid than either Constantinople or Egyptian opium. It yields about 8 per cent. of morphia on the average. Of *Constantinople opium* there are two sorts: one in large irregular cakes; this is of good quality. The other, in small flattened regular cakes, of a lenticular form, from 2 to $2\frac{1}{2}$ inches in diameter, covered with a poppy-leaf. *Egyptian opium* occurs in round flattened cakes of about 3 inches diameter. It is inferior to the Constantinople opium, and is said to yield only $\frac{5}{7}$ths of the morphia obtained from Smyrna opium. *Trebizon* or *Persian opium*, also inferior, has been imported in the form of cylindrical sticks, each enveloped in a smooth shiny paper tied with cotton. Of *Indian opium* there are 3 varieties, the *Malwa*, *Benares*, and *Patna*, the two latter being included under *Bengal opium*. The latter is imported in balls of about $3\frac{1}{2}$ lbs. weight, packed in chests of 40 balls each. "The balls are hard, round like cannon balls, and about the size of a child's head. Externally, each ball is made of poppy petals, firmly agglutinated by a paste, called *lewa*, to form a firm but laminated envelope, weighing about 14 oz. On cutting through this the opium is found to be quite soft, homogeneous, apparently quite pure, and to have the consistence of a soft extract. Its colour is blackish brown. Its odour and taste are strong and pure opiate. On exposure to the air this opium speedily becomes covered with mouldiness." It is said that this opium contains from $2\frac{1}{2}$ to 3 per cent. of morphia, but Dr. Pereira regards this as being considerably below the truth. There is also an *English*, a *French*, and a *German* opium, but the quantities are inconsiderable although the qualities are good.

Opium has long been known for its energetic action on the animal system. When taken by man in small doses, as from $\frac{1}{4}$ grain to 1 grain, it generally acts as a stimulant, and produces pleasurable excitement; but the dose must be increased in order to produce the same effects. When a full medicinal dose (as from 2 to 4 grains) is given, the stage of excitement is soon followed by that of depression. The skin becomes hot, the mouth and throat dry, the appetite diminished, the thirst increased, and nausea or vomiting is frequently induced. A state of torpor then comes on, followed by sleep with pleasing or frightful dreams, and on waking there is frequently nausea, furred tongue, headache, and listlessness. A larger dose produces death in persons not accustomed to it; but, unfortunately, the habit of taking opium habitually (*opium-eating*) is not uncommon even in England. It is first resorted to for the relief of bodily suffering, and the habit, once began, is seldom relinquished. The following description may be taken as a warning:—"The habitual opium-eater is instantly recognised by his appearance. A total attenuation of body, a withered, yellow countenance, a lame gait, a bending of the spine, frequently to such a degree as to assume a circular form, and glossy deep-sunken eyes, betray him at the first glance. The digestive organs are in the highest degree disturbed, the sufferer eats scarcely anything, and has hardly one evacuation in a week: his mental and bodily powers are destroyed, he is impotent. By degrees, as the habit becomes more confirmed, his strength continues decreasing, the craving for the stimulus becomes even greater, and to produce the desired effect, the dose must constantly be augmented."

Large quantities of opium are consumed in China and the islands of the Indian Archipelago, by smoking. "The smokable extract, called *chandoo*, is made into pills about the size of a pea. One of these being put into the small tube that projects from the side of the opium pipe, that tube is applied to a lamp, and the pill, being lighted, is consumed at one whiff or inflation of the lungs, attended with a whistling noise. The smoke is never emitted by the mouth, but usually receives vent through the nostrils, and sometimes, by adepts, through the passage of the ears and eyes. The residue in the pipe is called *tye-chandoo*, or fæcal opium, and is used by poor persons and servants." The effects on the system are extremely baneful.

The peculiar properties of opium are due to the presence of several alkaloids, the chief of which are *morphine*, *narcotine*, and *codeine*. Others of less importance are obtained in small quantity, viz. *thebaine*, or *paramorphine*, *narceine*, *pseudomorphine*, and a crystalline substance, containing no nitrogen, which acts the part of base; it is called *meconine*.

(1) Texier, Journal de Pharmacie, Quoted by Dr. Pereira, Elements of Materia Medica, vol. ii. 1842.

Morphine. In order to extract the morphine, the opium is cut into thin slices, which are macerated in water until sufficiently soft; it is then made up into a pulp with more water, put into bags, and subjected to strong pressure. The marc, or contents of the bags, are treated with water and again pressed. The expressed liquid is evaporated to the consistence of an extract, from which the salts of morphine are dissolved out by means of a small quantity of water, leaving the greater portion of the narcotine mixed with a brown matter. Trial is made with a small portion of the liquor how much ammonia is required exactly to precipitate the morphia: the third of this quantity is first added, which throws down an impure morphia, dragging with it nearly all the colouring matter. The remaining portions of the ammonia precipitate nearly pure morphine. This is treated with dilute alcohol (20° Baumé), which does not dissolve any sensible quantities of morphine, but removes almost entirely the resinous matter with which it is entangled. The residue is treated with boiling alcohol, of 35° Baumé, which dissolves the morphine, but deposits the greater portion of it in cooling. Three-fourths of the alcohol are separated by distillation, and the remainder gives up the morphine; but in order to obtain this base completely pure, it must be dissolved in weak hydrochloric acid, crystallized, and decomposed again by means of ammonia. Morphine crystallizes with facility. Its crystals consist of $C_{34}H_{18}NO_6+2HO$: they readily part with the two equivalents of water by the action of heat, and can then be raised to the temperature of 572° without decomposition. Cold water dissolves about $\frac{1}{1000}$th of morphine; warm water nearly double that quantity; the solution restores the blue colour to reddened litmus. Dilute alcohol (20° Baumé) dissolves only a small quantity of morphine; boiling alcohol (35° Baumé) dissolves $\frac{1}{30}$th of its weight, but the greater portion of the morphine crystallizes on cooling. Ether has scarcely any action on it. A concentrated solution of caustic potash dissolves morphine without change, a property which allows this base to be separated very exactly from narcotine, which is not soluble in alkaline menstrua; morphine dissolved in acidulated water and exposed to the action of polarized light turns the plane of polarization to the left: its salts exert the same action. Morphine forms with acids crystallizable salts, which are soluble in water and in alcohol, but insoluble in ether. The *hydrochlorate* of morphine is used in medicine, it crystallizes in slender colourless needles, arranged in tufts or stellated groups: it is soluble in about 20 parts of cold water, and in its own weight of boiling water. The *sulphate*, *nitrate*, and *phosphate* are crystallizable salts. The *acetate* crystallizes with difficulty.

Narcotine. This is obtained from the *marc*, or insoluble portion of opium left in the preceding operation. This is treated with ether, which dissolves a mixture of narcotine and porphyroxine in which the narcotine prevails. Fresh opium may even be treated in this way; the salts of morphine remain behind, and the ether contains with narcotine and porphyroxine a certain quantity of meconine. The ether is distilled at the water bath; the residue is treated with water, which dissolves the meconine; and lastly, the narcotine and porphyroxine are dissolved out by dilute hydrochloric acid. The solution on being evaporated leaves hydrochlorate of narcotine, and the hydrochlorate of porphyroxine remains in the mother liquor. The hydrochlorate of narcotine decomposed by ammonia gives narcotine in an isolated form: it may be purified by crystallization in alcohol. It crystallizes in small colourless brilliant prisms, which are nearly insoluble in water. The basic powers of narcotine are very feeble, and although freely soluble in acids it seldom forms with them crystallizable compounds. Narcotine consists of $C_{46}H_{25}NO_{14}$: it rotates to the right as do also its salts.

Codeine, $C_{34}H_{19}NO_5$. This substance remains in the liquors after morphine has been precipitated by ammonia. These liquors are evaporated, caustic potash added, and the evaporation continued to dryness. The residue is treated with ether, which dissolves the codeine, and this crystallizes by spontaneous evaporation into colourless transparent octahedrons. Codeine is much more soluble in water than the other alkaloids of opium: it dissolves in 80 parts cold water and 20 of boiling water, and it is very soluble in alcohol and ether: it has a strong alkaline reaction, and forms crystallizable salts.

Meconine (from μήκων, a poppy) is obtained by digesting opium in cold water, filtering the infusion, concentrating it by evaporation, and adding ammonia as long as a precipitate is produced. After some days the supernatant liquid is poured off gently, evaporated to the consistence of syrup, and left in a cool place for 15 or 20 days, when it deposits granular crystals, which are collected, drained, pressed, and dried by a gentle heat. They contain meconine, narceia, and other substances; they are boiled in alcohol, and the solution is evaporated to about one-third its bulk, when on cooling it deposits crystals, which are collected, dissolved in boiling water, and filtered with animal charcoal; white crystals are obtained of meconine and narceia; ether dissolves the former and leaves the latter: on evaporating the ethereal solution, the meconine remains. It is white, inodorous, slightly acrid, soluble in water, alcohol, and ether, and crystallizable.

Meconic acid, $C_{14}HO_{11}3HO$, is also obtained from opium. When chloride of calcium is poured into an infusion of opium, a precipitate of impure meconate of lime is formed, which is first washed with water, then with alcohol. After this it is treated with 20 parts warm water to which are added 3 parts of hydrochloric acid: the filtered liquor leaves on cooling an acid meconate of lime. This salt is digested with a similar quantity of warm acidulated water, and meconic acid separates on cooling. This operation must be repeated once or twice to obtain the acid entirely free from lime. Meconic acid crystallizes in small colourless pearly scales, which dissolve in 4 parts of hot water. It has an acid taste and reaction,

forms soluble compounds with the alkalies; and insoluble salts with lime, baryta and the oxides of lead and silver. With a salt of peroxide of iron, meconic acid strikes a deep blood-red colour, resembling that developed under similar circumstances by a sulphocyanide; but the addition of corrosive sublimate bleaches the sulphocyanide, but has little effect on the meconate.

There are many other substances derived from or connected with opium, for an account of which we must refer to chemical works.[1]

ORCHIL. See ARCHIL.

ORCINE. See ARCHIL.

ORE. See METALLURGY—MINING.

ORGAN. The organ is a complex wind-instrument, consisting of a large number of pipes of different sizes, materials, form and arrangement, made to sound by means of compressed air supplied to them through certain channels by bellows. There are different kinds of organs, such as the small *bird-organ*, the *chamber-organ*, the smaller *chapel-organ*, and the great *church-organ:* there is also the *barrel-organ*. The organ is so well known by its external form, and the sublime and beautiful effects which it produces in our public worship, that few persons will fail to be pleased with a knowledge of the numerous ingenious mechanical arrangements which belong to its internal structure, and which enable a single performer to throw out the floods of sound and intricate harmonies of a full orchestra.

The early history of the organ is obscure. It appears that a small and imperfect instrument of the kind was known to the ancients: thus we read of *hydraulic* organs and *pneumatic* organs, but as the passage of water through the pipes would not produce musical notes, we are led to believe that water was employed as a moving power to impel wind into the pipes. The term *pneumatic* is still sometimes applied to the modern organ, to indicate that wind is the *moving power*, so to speak, of the instrument.

With respect to the term *organ*, the Greek word *ὄργανον*, the Latin *organum*, and the English *organ*, originally signified an instrument or machine of any kind. The term was afterwards limited to musical instruments used to accompany the voice in singing; it was afterwards restricted to wind-instruments, and in modern times to the instrument now recognised as such. The term occurs three times in our version of the Old Testament, viz. in Gen. iv. 21, Job xxx. 31, and Psalm cl. 4. The instrument here alluded to was probably the *syrinx*, *Pan-pipes*, or *mouth-organ*, consisting of several reeds, of different lengths, joined together, closed at one end; and the sound produced by directing a thin stream of air from the lips into the open end. This simple instrument, and the bagpipes, were probably the immediate predecessors of the organ.

The earliest notice that can be at all relied on of the introduction of the organ into the churches of Western Europe is, that about the year 757, the emperor Constantine V. presented one to Pepin, king of France. In 812 Louis-le-Débonnaire caused one to be built at Aix-la-Chapelle on a Greek model, and this is supposed to have been the first that was used with bellows without the use of water. Previous to the tenth century organs were common in England. St. Dunstan gave one to the abbey of Malmesbury. Elfeg, bishop of Winchester, in 951, obtained one for his cathedral, the largest then known. The organs of this period were rude in construction: the keys were 4 or 5 inches broad, and were struck with the clenched hand after the manner of carillons: the pipes were of brass, harsh in sound, and the compass, even so late as the twelfth century, did not exceed 12 or 15 notes. About this time half-notes were introduced at Venice, at which place was also made, in 1470, by Bernhard, a German, the important addition of *pedals* or *foot-keys*. The gradual improvements in the construction of organs may be traced in those erected at Dijon in the 13th century, at Halberstadt in 1360, and at Nuremberg in 1468, about which time large pipes of 16 and 32 feet began to be made. The description of an organ at Breslau, in 1596, shows that at that time all the principal stops now in use were known, and that the present general arrangement and details of a large organ were then adopted. After this time the chief improvements were mechanical.

Little is known respecting organs in this country from the time of the Reformation to the reign of Charles I. There was a great demolition of organs in the time of the Puritans; our organ builders became carpenters and cabinet-makers, so that at the Restoration only four organ builders of eminence survived. This led to the introduction of foreign artists, such as Bernard Schmidt (called "Father Smith"), and his two nephews; the elder Harris, and his son Renatus. Some of the organs of these skilful mechanicians still exist in London, Oxford, &c. Schreider, Smith's son-in-law, built the organ in Westminster Abbey, and that at St. Martin's in the Fields. Snetzler, Byfield, and others, and, at a later period, Green, Avery, Gray, Elliot, &c., were celebrated as organ builders. By these makers, and some of the most eminent of Germany and Italy, the mechanism of the modern organ was greatly improved. Among the earliest famous builders in Italy in the 15th and 16th centuries is the family of the Antegnati of Brescia. In the 18th century the most celebrated builders were Serassi of Bergamo, and Callido of Venice: each constructed upwards of 300 organs.

When a person, unaccustomed to the study of mechanism, surveys the interior of an organ case, the arrangement appears to be so exceedingly complex that he is likely to turn away, impressed with the idea that it cannot be understood except by professional men. And yet the principle of the organ is sufficiently simple: only, this principle being carried out to its utmost extent, a complex appearance does arise from the multiplication of similar or nearly similar parts, and from the contrivances made for the sake of economy of space. In a great church organ, such as we propose very briefly to describe, there are

(1) See Gregory's Outlines of Chemistry. Brande's Manual of Chemistry, and Pereira's Materia Medica.

several thousand pipes, and arrangements for enabling the performer to operate upon any single pipe of the number without interfering with the others: hence there are numerous levers and rollers, quadrants and rods, slides and partitions. Now to take the simplest case: In order to make one pipe sound or *speak*, there must be, 1, a bellows for supplying condensed air or wind; 2, a channel for conveying it to the pipe in question; 3, some contrivance, such as a valve, for admitting the wind to this pipe when it is required to speak, and for cutting off the supply when required to be silent; 4, a lever for opening or shutting this valve. These, and other contrivances yet to be named, for producing variety of effect, loudness or softness, qualities of tone resembling various musical instruments, &c., necessarily require the introduction of a good deal of mechanism and a great repetition of parts. We will endeavour so to describe the separate parts of the organ, as to give the reader a general idea of the construction of this instrument.

And first with respect to the *pipes*, the grand assemblage of which constitutes the organ. There are two general descriptions of pipe, the *mouth* or *flute* pipe (technically *flue*) and the *reed* pipe, each comprising several different species.

Mouth-pipes, or pipes with a mouth and lips similar to the flageolet, may be of wood or metal: they differ somewhat in shape, but are formed on the same principle. The shape of the metal mouth-pipes is well known, since they are used to decorate the front of the organ-case. The wooden mouth-pipes consist each of a four-sided trunk or chest, formed by glueing 4 plane boards together: the cross section is not square, but oblong, one side being to the other in the proportion of 5 to 4. The interior is usually sized with glue. The upper extremity may be open, or closely stopped by means of a plug, called a *tompion*, *t*, Fig. 1538, made to fit air-tight by being covered with leather. The other end of the tube is also closed by means of a block *b*, on which 3 of the walls are glued, except at the narrow aperture or mouth *m* across the front wall. The mouth is formed by cutting off in a sloping direction or bevel a portion of the front wall, a little above the upper part of the block, so as to form a sharp edge with the back or inner surface of the wall: this sharp edge is called the *upper lip* or *wind-cutter*. The side and back walls also embrace another block *p*, arranged so as to form with *b* a narrow space. The foot *f* of the pipe is fixed in this lower block: this foot is a hollow cylinder open at both ends, the lower end formed so as to fit into the apparatus which supplies the pipes with wind. The front of the pipe, from the mouth downwards, is covered by the cap *c*, Fig. 1537, consisting of a piece of mahogany somewhat thicker than the walls. It is hollowed out so as to leave edges for glueing upon the edges of the side walls and the block into which the foot is inserted, but leaving the aperture quite free. When the cap is screwed on, a thin aperture is left between it and the block *b*, called the *plate of wind*, which, when the foot *f* is supplied with air, is forced in a thin stream against the upper lip or wind-cutter; and the vibrations which it thus receives it imparts to the whole column of air in the pipe; the result of which is a musical note, depending for its pitch upon the length of the column thus set in motion. A good quality of sound is produced by what is called *voicing* the pipe; that is, before the cap is put on, the upper corner or edge of the block is slightly pared away opposite the upper lip, so as to direct the wind against its inner edge. Skill and experience are required in this operation; for if too much or too little be pared away, the pipe will be slow to speak, or not speak at all, or speak badly. The upper part of the block is also toothed with the edge of a file into thin cuts or lines, forming acute angles with the under lip, for the purpose of dividing the plate of wind; for if suffered to strike against the upper lip undivided, it would form an unpleasant chirping at the commencement of the note. The width of the mouth, or the distance of the upper lip from the plate of wind, is of importance to good speaking: if too great, the pipe may be slow to speak, or not speak at all; if too narrow, an open pipe may give the octave or double octave, and a stopped pipe the twelfth of the note intended to be produced.

Fig. 1537. *Fig.* 1538.

The pitch of the note depends on the length of the pipe above the mouth. If the length be doubled, the vibrating column of air is also doubled, and the pipe gives the octave lower; so by halving the length of a pipe, it speaks an octave higher. If we call the length of the pipe for the lower octave 1, then that of the octave above will be $\frac{1}{2}$, and the lengths of the pipes required to fill up the interval will be respectively, $\frac{8}{9}$ths, $\frac{4}{5}$ths, $\frac{3}{4}$ths, $\frac{2}{3}$ds, $\frac{3}{5}$ths, and $\frac{8}{15}$ths. So also if we represent the number of vibrations required to produce the lower octave by 1, double that number, or 2, will represent the number of vibrations in the octave above; and those of the intermediate number of vibrations between the two octaves will be represented by the reciprocals of the above fractions, viz. $\frac{9}{8}$ths, $\frac{5}{4}$ths, $\frac{4}{3}$ds, $\frac{3}{2}$ds, $\frac{5}{3}$ds, and $\frac{15}{8}$ths. The lowest audible note, however, is not produced by 1 vibration per second, nor by its octave 2, nor by its octave 4, nor by 8, but by 16 *single* or 32 *double* vibrations[1] per second. This forms what is called the C below, and is produced by an open pipe 32 feet long. The octave of this, 64 vibrations per second, is the lowest C of a grand pianoforte, and is produced by an open pipe 16 feet long. Then we have—

(1) This refers to a stretched string, in which at each *double* vibration two impulses are given to the air, one on each side of the axis of the string: one such impulse constituting the *single* vibration.

128 vibrations	= the lowest note of the violoncello	an open pipe 8 feet long	
256 ,,	= tenor C, the lowest note of the viola	4	,,
512 ,,	= middle C, the note of the C clef...	2	,,
1024 ,,	= C on the 3d space in the treble clef	1	,,
2048 ,,	= C in alt....................................	½ foot long.	

In speaking of the stops of an organ, it is usual to express the notes by the lengths of pipes corresponding to them: thus the lowest C of a grand pianoforte is called on the organ 16-feet C; middle C is called 2-feet C, and so on. All this refers to open pipes. The effect of stopping them at the top is at once to lower their pitch a whole octave; and the reason is evident: the wind not being able to escape at the top of a stopped pipe, returns, and gains an exit at the mouth, thus actually *doubling* the length of the vibrating column, and making its vibrations proportionally slower. This valuable property allows of considerable economy of space in the construction of the organ, because a stopped 16-feet pipe emits the same note as an open 32-feet pipe, and a stopped 8-feet pipe gives the same note as an open one of 16 feet, and so on.

With regard to the quality of the tone or *timbre* of a pipe, this depends greatly on the size of the tube; and as it is of importance to have the same quality for all the notes of the same stop, scales of sizes have been formed for the use of the organ-builder: these scales vary with the size of the organ. The kind of wood used has an influence on the tone of wooden pipes. Mahogany or wainscot pipes give a clearer tone than pipes of fir or other soft wood; but the latter are more mellow. The notes are regulated as to loudness by enlarging or diminishing the aperture in the foot, whereby more or less air is admitted. The stopped pipe is tuned by means of the tompion or plug. By pushing this deeper into the tube, the effective length of the column of air is shortened, and the resulting note will be more acute; by drawing up the plug, the note will be graver.

The structure of metal mouth-pipes, Figs. 1539, 1540, is somewhat different. They are nearly closed

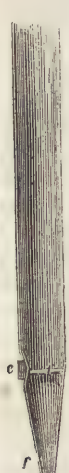


Fig. 1539.

Fig. 1540.

Fig. 1541.

Fig. 1542.

at the base of the cone by a thick metal plate or *languette, l,* Fig. 1539, answering the purpose of the block in the wooden pipe. A thin slit is left, by means of which a plate of wind is formed with the under lip. The voicing is performed by making parallel notches on the bevelled surface at an angle with the axis of the pipe. The ears *e e* are of soft metal, so that by bending them more or less over the mouth the tone is modified as required.

Another form of mouth-pipe is the *chimney top,* Figs. 1541, 1542. Such pipes have a small open tube *c* in the middle of the top plate, the effect of which is to make the note considerably sharper than if quite stopped; an effect which is sometimes produced in stopped wooden pipes by boring a small hole through the tompion.

The structure of *reed-pipes* is very different from that of mouth-pipes. In reed pipes, Fig. 1543, there is a brass cylindrical or slightly conical tube or *reed r,* with a longitudinal narrow opening in front. The lower extremity is cut slanting upwards and backwards, and is closed by a piece soldered on it. The long opening is covered by a thin plate of metal *t* called a *tongue:* it is kept firmly to the reed at its upper end, but is free at the lower end, and slightly curved away from the reed. This little piece of apparatus is firmly fixed to a solid block *b,* the open end passing through it. Through the block also passes a wire *s s′*, bent up so as to press firmly against the top of the tongue and keep it close to the reed; so that by pushing down or drawing up this *tuning wire,* as it is called, the free part of the tongue is made shorter or longer. The block containing the reed, &c. is inserted in or just above the cone or foot of the pipe, the large end of which is thus completely closed. The wind is sent in at the point of the cone. The tube above the cone is variously shaped, and upon it depends the *quality* of tone in reed-pipes, the *pitch* depending entirely on the length, thickness, and elasticity of the tongue of the reed. The first action of the wind is to press the tongue against the reed and close the opening; the elasticity of the tongue immediately causes it to rebound and pass beyond its position of repose: it then returns, and, as the wind still exerts its force, it is again driven against the edges of the reed, and thus a musical note is produced, which is acute or grave according to the length of tongue left free to vibrate below the tuning spring. The structure of the reed was improved many years ago by M. Grenié, who, instead of making the tongue beat on the edges of the opening, formed it just within the opening, so as nearly to close it, and thus to play freely backwards and forwards in and out of the same. The tongue *t*, Fig. 1544, is a perfectly flat plate of brass, rectangular in shape, and the tuning spring *s s′* is very firm and solid, so as to stop the tongue at the proper length and fix the point from which it is to vibrate. The tongue thus playing rapidly in and out of the opening of the reed, instead of beating on the reed itself, throws the current of

Fig. 1543.

Fig. 1544

air which passes through the reed into vibration, as in the beating reed, but produces a more sweet, harmonious, and equal tone, since the plate, instead of beating against wood or metal, the resistance of which is sudden and irregular, only causes the air, which is perfectly homogeneous, compressible, and elastic, to recoil upon itself; and hence the sound is as sweet as in mouth-pipes. By having a firm spring, the pipe cannot *octave* under increased pressure of wind, but can only become increased in loudness. The free reed is less liable to get out of tune than the beating reed. Moreover, the latter gives only one quality of tone, of the same degree of loudness, while the free reed admits of *expression*, that is, by varying the pressure of the wind, *crescendo* and *diminuendo* effects may be produced. The free reed attracted but little notice for many years after its invention; but it is now used in organs by foreign builders. The French and German organs in the Great Exhibition contained free reed stops; but the principle has not yet been adopted by English organ-builders.[1]

The air which causes the reeds to vibrate, escapes by open tubes increasing into a cone, and terminated in a hemisphere, a form which gives roundness and force to the sound. The length of each tube is equal to that of the tongue. In constructing his reed stops, M. Grenié began withthe lowest octave of which C is unison with an open mouth-pipe of 8 feet: and he had constructed a certain number of notes by giving the wind to his reeds by port-vents or sockets of the same length, Fig. 1545. But when he came to the first notes of the tenor, continuing to make his port-vents in the same manner, the reed would not speak. He increased and diminished the wind, lengthened and shortened the tongue, to no purpose. At last, supposing the length of the tube which conveys the wind to the reed might have some influence on its motion, he substituted for his fixed tubes, one sliding within the other, so that he could gradually vary the total length; and he continued his trials until the reed gave a brilliant, pure, and sustained sound. He also found, that in order to obtain the fullest tenor, it was necessary to make the port-vent much longer than for the note immediately preceding, and this length went on diminishing for the more acute octaves, as shown in Fig. 1546. The tops of his pipes were curved as at T T′ T″, which seemed to indicate that by prolonging this curve, dimensions would be obtained most favourable for the pipes of the first octave, which at first were made of equal length This led to no advantage, but on the contrary, the sounds were bad. He therefore kept to his first construction, and purposed to make his port-vents double, and sliding, so as to be able to give to each the best length. Reed-pipes on this model give the note of the 16-foot open pipe with remarkable distinctness, power, and regularity. The tongue is a plate of copper 9·46 inches long, 1·38 inches broad, and 0·118 inch thick. Its vibrations are described as being so powerful, that they cause to tremble the pipe, the port-vent, and every elastic body in the vicinity.

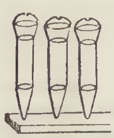


Fig. 1545.

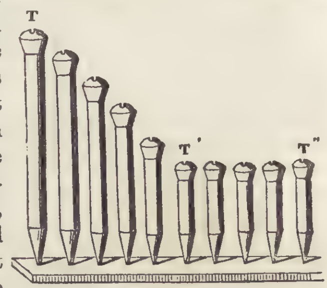


Fig. 1546.

Now, it will be evident, that with as many sets of pipes as there are octaves in the key-board of the pianoforte, each octave giving the 12 notes of the chromatic scale, an organ of the simplest kind would be formed; and if the key-board of such an instrument were as extensive as that of the pianoforte, it would be as complete as that instrument as far as regards *scale*. But in an organ there are a great many sets of pipes or *stops*, as they are called, the corresponding notes of which agree in pitch, but differ in the timbre or quality of tone. Each stop, then, is a range of pipes of the same quality of tone extending throughout the compass of the organ. When a certain stop is drawn, the keys will play throughout on pipes of that character of which the stop consists. Stops differ in pitch and in timbre, so that the same key will sound different notes, according as different stops are drawn. The mode in which stops are designated, "is by stating the interval which any note of the given stop makes with the fundamental note corresponding to the key struck. Thus, when the key *middle* C, or 2-foot C, is struck, a certain stop will sound the G at an interval of a twelfth above: this stop is therefore called the *twelfth*. Another stop will sound the C two octaves above, and is therefore called the *fifteenth*. The stops which sound the fundamental note itself, would be on this principle designated *unison*, and those sounding an

(1) Mr. Bishop informs us that the free reed has from time immemorial been used by the Chinese in a small instrument called the *Chinese organ*. M. Grenié introduced the free reed in 1810, and constructed two instruments on this principle, one of which was sent to the Conservatoire des Arts, &c. In 1827, three free reed stops were introduced into the organ at Beauvais Cathedral, and in 1829, M. Sebastian Erard introduced a free reed stop into an organ built by him for the Tuileries: in this stop the expression was made to depend on the touch. After this the application of the free reed to the organ was forgotten; but the reed itself became in a very remarkable manner the basis of a variety of new instruments, such as the *accordion*, Wheatstone's *æolina*, which soon led to that exquisite little instrument, the *concertina*. The attempts made to improve the accordion by enlarging and completing its scale, made it so unwieldy that it naturally took the form of an organ with a free reed stop, without pipes, with bellows worked by the foot: such was Mr. Green's *seraphine*. Varieties of this instrument have since appeared, under the forbidding names of *æolophon*, *physharmonica*, *æolomusicon*, and *poikilorgue*; and the more euphonious appellations of *harmonium*, *melodium*, and *symphonium*. We have also a *folding harmonium*, and an *orgue de voyage*, or travelling organ. The folding harmonium exhibited by Messrs. Wheatstone at the Great Exhibition has a compass of 5 octaves, and when expanded for use is 41 inches long, 10 inches deep, and 25 inches high. It is ingeniously contrived so as to fold in the middle of the clavier, and also underneath, by which its dimensions are reduced to 21 inches long and 10½ inches high, or a little larger than an ordinary writing-desk.

octave above it, would be called *octave.* For the stops sounding an octave below the fundamental note, the word *double* has been used, and though not correct in principle, it may be considered as sanctioned by custom."[1] The tone of every key in a large organ consists of notes of several pitches combined, so as to blend together into one sound: that is, in addition to the fundamental note there are other notes forming harmonic intervals with it. Thus, the fundamental note (8 feet pipe), its octave (4 feet), its twelfth ($2\frac{2}{3}$ feet), and fifteenth (2 feet), form a good organ of moderate power. But in large organs there are also *compound* stops, consisting of various combinations of the intervals of the major common chord, or third, fifth and eighth in octaves above the fifteenth, producing by their combination great brilliancy of sound. But in ascending in the scale, the effect was found to be too shrill, and accordingly *weight* was given by adding the octave below, or 16-feet stop. This not only produced a brilliant and powerful effect adapted to large edifices, but allowed of the introduction of other intervals, such as the fifth ($5\frac{1}{3}$ feet), and tenth ($3\frac{1}{5}$ feet) of the fundamental note. The small compound stops are usually so arranged, that one draw-stop serves for several ranges of pipes. The reeds, which greatly reinforce the power of a full organ, are used in the form of 16 feet (double), 8 feet (unison), 4 feet (octave), and sometimes 2 feet (fifteenth) stops. In addition to these, there are *solo* or *fancy* stops, generally either 8 feet or 4 feet in pitch, both of the flute and the reed kind. The variety is given to the flute stops by the scale, the material, or the form of the pipe, and by the voicing. "The delicate silvery sound of the stop called the *dulciana*, is produced by an open metal pipe of very small scale; and an agreeable kind of tone has been lately obtained by a pipe pierced with a hole in its side. A fine stop used by the French, is produced by making the pipes *overblow*, as it is called, so as to sound an octave higher than the note due to their length." Among the reeds named from the instruments which they imitate, the effect is produced chiefly by varying the form of the tube. The ordinary tube is conical; the *oboe* stop, Fig. 1547, has a bell mouth, and a conical tube, and gives a tone resembling the oboe. Figs. 1548, 1549, show the form of the *trumpet* pipe. Fig. 1550, the *cromorna* or *cremona*, which has a sound resembling that of a clarionet. Fig. 1551, the *bassoon*, and Fig. 1552, the *vox humana*, from its supposed resemblance to the human voice.

Referring to Fig. 1555, which represents the end pipes of the rank of pipes or stops mounted on the sound board over the wind chest, &c., we will briefly recapitulate the most usual organ stops: these are, I. *Open diapason* (marked O D in the engraving); this consists of metal mouth-pipes, open at the upper end, and extending through the whole scale of the organ, as its name *diapason* implies. II. *Stopped diapason* (S D); mouth-pipes generally of wood, their pitch being in unison with I.: they are plugged at the upper end. III. *Double diapason;* wooden mouth-pipes open at the upper end, their pitch being an octave lower than I: they are usually confined to the two lowest octaves of the organ's compass. In the largest organs the gravest sound is produced by an open pipe 32 feet long. IV. *Principal* (marked P); metal mouth-pieces, the pitch of which is an octave above I. This is the first, or medium stop, which is tuned, all the other stops being tuned from it. V. *Dulciana;* a metal mouth-pipe stop, tuned in unison with I. The length and narrowness of its pipes produce the sweetness of tone from which it is named. VI. *Twelfth* (marked 12); metal mouth-pipes, tuned a twelfth above I. VII. *Fifteenth* (marked 15); metal mouth-pipes, tuned an octave above IV. In some organs are stops named *tierce* or *seventeenth, larigot* or *nineteenth, twenty-second, twenty-sixth, twenty-ninth, thirty-third*, &c., tuned at these intervals above I. VIII. *Flute;* metal and wood mouth-pipes, (more generally wood,) in unison with IV. IX. *Trumpet* (marked T); reed-pipes, of metal, in unison with I. X. *Clarion* or octave trumpet stop; metal reed-pipes, tuned an octave higher than IX. XI. *Bassoon;* reed-pipes, in unison as far as their compass reaches with I. XII. *Cremona*, or *krum-horn;* reed-pipes, in unison with I. XIII. *Oboe;* reed-pipes, in unison with I. XIV. *Vox-humana;* reed-pipes, in unison with I.

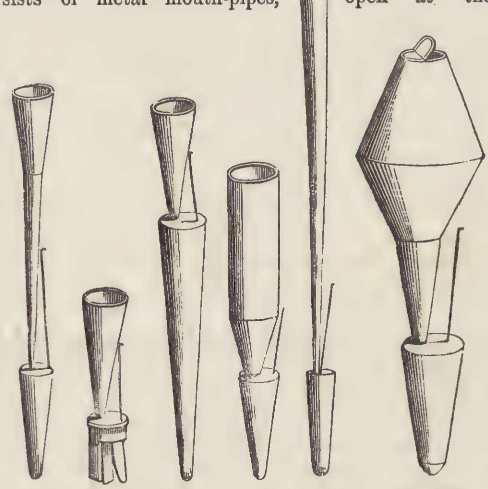


*Fig.*1547. *Fig.*1548. *Fig.*1549. *Fig.*1550. *Fig.* 1551. *Fig.* 1552.

Among the compound stops are, I. The *sesquialtera.*

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(1) Newton's London Journal, vol. xxix. In the papers contained in this Journal on the Great Exhibition, are some admirable Essays on the "Musical Instruments" exhibited. Those on the organ have furnished us with some valuable hints. While on the subject of references, we must notice the great deficiency of works on the organ in the English language. There are some good essays on the organ in Rees's Cyclopædia, the Edinburgh Encyclopædia, and the Encyclopædia Britannica, all of which we have consulted, and are indebted to the first two for many of our figures. The French and Germans are singularly rich in works on the organ. In the former must be noticed, L'Art du Facteur d'Orgues, by Bedos de Celles, a Benedictine Monk, in two folio volumes, Paris, 1766—1770, with 137 plates. In German, the Abbé Vogler has several works on Organ Building. But many of the fine treatises which might be quoted, are not accessible to the general reader. We therefore recommend him to a cheap but excellent work in the Encyclopédie Roret, largely compiled from the work of Bedos de Celles, and entitled Nouveau Manuel Complet du Facteur d'Orgues, par M. Hamel. 3 vols. 1849, with an Atlas, containing nearly 1,000 figures in 43 large plates.

(marked Sq.), consisting of 4 or 5 rows of open mouth-pipes, at the intervals of seventeenth, nineteenth, twenty-second, twenty-fourth, or twenty-sixth above the open diapason. II. The *cornet,* a stopped diapason, principal, twelfth, fifteenth, and seventeenth; but this is now altogether gone out of use in England. III. *Mixture* or *furniture* stop, F, consisting of several ranks of pipes nearly the same as those of the sesquialtera, but some of higher pitch.

The different series of stops are so distributed in a large organ as to form three or four separate organs, each of which has a distinct row of finger keys, its own separate wind-trunk, wind-chest, sound-board, &c. And these three or four distinct organs comprised in one, have been recognised as such by having different names assigned to them; thus we have the *great organ,* the *choir organ,* and the *swell;* to which may be also added the *pedal organ,* or *foot keys* for acting on the larger pipes. The most important of the three key-boards is that of the *great organ:* it contains the principal stops for giving power; and is generally the lowest but one. The compass is 4 or 4½ octaves, beginning with C (8 feet) as the lowest note. In French organs the principal reed-stops, and some others of considerable power, are made into a separate organ, which receives a different pressure of wind. Its key-board, called the *clavier de bombarde,* is immediately above that of the *grande orgue.* The lowest row of keys generally belongs to the *positif* or *choir* organ. It contains stops of a light character, and solo stops. The great organ is situated in the forepart of the case, in order that its largest pipes may be planted in the ornamental front, and that it may have a louder effect. The choir organ is sometimes placed in front of the great organ in a separate case at the back of the player, and is hence sometimes called the *chair* organ. The upper row of keys belongs to an organ called the *swell.* It consists of an organ shut up in a box closed on 3 sides and having in front Venetian shutters, or moveable louvre boards, arranged so as to open and shut by means of a pedal. When shut, the sound appears to be muffled and distant, but on being gradually opened, the sound becomes louder. In this way, the effect of crescendo and diminuendo is produced. The swell contains the same kind of stops as the great organ, but on a smaller scale. Stopped pipes are used for the lower notes for economy of space. The pedal organ, played by the feet, consists of 32-feet stops, with 16-feet stops, 8-feet stops, and smaller sizes. There is not always, or, indeed, often a separate pedal organ, the pedals being used for the larger pipes of the great organ called *pedal pipes* (16-feet).

In Messrs. Ducci's organ in the Exhibition, the pedal notes, 12 in number, beginning with 16-feet C, are said to have been all produced from one pipe about 4 feet long, contained in the stool on which the organist sat. It is stated that the makers have "found a means of so varying the proportions and make, as to cause a stopped pipe of 4 feet long to sound a 16-feet note, of 8 feet, a 32-feet note, of 2 feet, an 8-feet note, and so on; and, secondly, they have made the same pipe speak different notes, by opening holes situated at certain distances in one of its sides, on the principle of the flute and other orchestral wind instruments. By applying, therefore, the pedal keys to move valves covering these holes, the whole range of an octave of pedal notes is produced by a simple and inexpensive means.

We have said that the bellows communicate by means of channels or wind trunks with certain *wind chests,* or reservoirs, and supply them with air: these wind chests distribute the wind to the various pipes when the finger or foot keys (*manuals* and *pedals*) are pressed down. With respect to the bellows, they may be *single* or *double,* the former being commonly used in church organs, and the latter in chamber organs. Single bellows consist of two oblong boards $b\,b'$, $b''\,b'''$, Fig. 1553; connected at b' by a joint of leather, and at the other 3 sides by thin folds of wood joined together with leather. The lower board is fixed, the upper move-

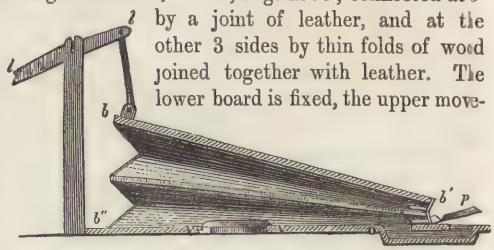


Fig. 1553.

able. In the lower board, at $v\,v$, is a hole, covered with a valve or pallet, opening inwards. At o is another aperture leading into a hollow box, $o\,b'''$, furnished with another pallet opening outwards. This box communicates with the wind trunk. When the upper board is raised by pressing down the lever $l\,l'$, the air rushes in at the aperture $v\,v$, and on letting go the lever the pressure of the weights on the upper board forces the air into the wind trunk at b''', the pallet at p preventing the return of the wind from the wind trunk when the upper board is raised. In order to keep up a constant supply of wind 2 or even 3 pairs of bellows are required: some of the large organs on the continent have as many as 12 pairs. This diagonal form of bellows is quite abolished in England.

Double bellows are made with 3 boards, $r\,b$, Fig. 1554, the riser, $m\,b'$ the middle, and $f\,b''$ the feeder boards. The air passes in at the valve v in the feeder. In the middle board at p is the pallet of com-

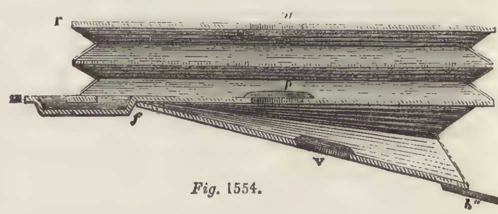


Fig. 1554.

munication, and at w in the riser is the waste pallet, which opens when the bellows are sufficiently full. The riser discharges air into the wind trunk at m.

The weight laid on the reservoir determines the pressure of wind, which is usually equal to that of a column of water about 3 inches high, or 15 lbs. per

square foot. It is now common to use different pressures of wind to different parts of the same organ, separate bellows being used for each pressure. In some of the organs in Germany the organ blower does not work the bellows levers, which project from the frame of the organ, by manual labour, but by stepping upon them one at a time as each lever rises, and allowing the weight of his body to bring it down, and so raise the bellows. In the Great Exhibition, in the bellows to the organs exhibited by Messrs Ducci of Florence, the feeder, consisting of a moveable board between two fixed ones, was double-acting; that is it supplied wind by its upward as well as downward motion.

Mr. Bishop, the celebrated English organ builder, (who has kindly conducted us through his workshops and explained to us the structure of various organs in progress of building, as well as in the finished state,) has introduced a variety of small but valuable improvements in the construction of organ bellows. Mr. Cumming, of Pentonville, has also invented what is called the *compensation fold*. It is evident, that when the bellows is falling under a certain load or weight of wind, and driving the air into the trunks, the collapsing of the folds of the bellows will diminish the capacity by a certain quantity plus that due to the falling together of the top and bottom boards, and thus lead to irregularities of pressure which disturb the estimate as to the weight required on the top board. The compensation fold offers an ingenious remedy for this defect. In this contrivance the folds of the bellows are so arranged, that while one fold collapses inwards the other fold collapses outwards, thus exactly neutralising the loss of capacity arising from the folds.

The bellows supply the wind chest W C, Fig. 1555, with condensed air. To the upper part of the wind chest is attached the *sound board* S B (as it is not very correctly called, for the pipes, not the sound board, produce the sound). The sound board is an oblong frame or box, the upper side of which is formed of stout board. On the under side of this board, in the direction from front to back, are a

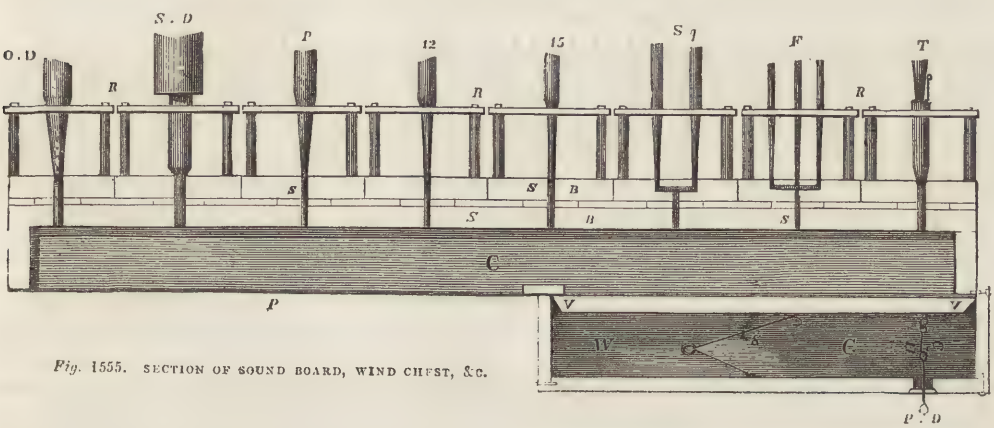


Fig. 1555. SECTION OF SOUND BOARD, WIND CHEST, &c.

number of grooves, each containing a thin bar of wood, thus dividing the box into parallel channels completely separated from each other. The number of channels corresponds with that of the finger-keys, and as there are 12 keys in each octave the number of channels is 12 multiplied by the number of octaves in the key board. Holes corresponding with the number of ranks of pipes are bored through the upper side of the sound board into each channel. The under side of the sound board is covered with parch-

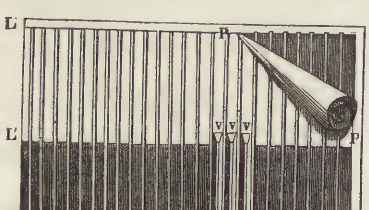


Fig. 1556.

ment or leather, P, Fig. 1555, and L P, Fig. 1556, except a space along the fore part, which is covered by the wind chest, and where each channel is closed by a valve or pallet V V, Fig. 1555, and *v p*, Fig. 1556, hinged at *v*, and pressed down to the groove by means of a spring S, Fig. 1555. The wind chest, which thus receives all the valves, is an air-tight box, so that the wind which is poured into it from the bellows through the wind trunks has no exit except through the channels of the sound board when the valves which cover them are raised. Each valve opens downwards and is connected with the key movement by a small brass wire hook, or *pull-down*, P D, Fig. 1555, which passes through a perforation in a brass plate upon the bottom of the wind chest.

On the upper side of the sound board, and in a direction at right angles to the channels above described, is another set of grooves, formed by screwing down thin pieces of hard wood, called *bearers:* the number of these grooves corresponds with that of the stops or sets of pipes. Fig. 1557 represents a portion of the upper surface of the sound board, divided into 4 longitudinal grooves by the bearers B B. In these grooves holes are bored through the top of the sound board, one into each channel below. The holes shown in the strip S S are in two lines for

the purpose of obtaining a greater distance between the holes of two adjoining channels, and also to guard against a defect called "the running of the wind," which will be explained presently. The holes

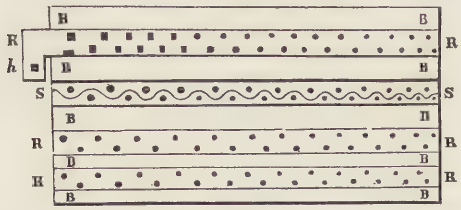


Fig. 1557.

diminish in size according to the size of the pipes. Over each groove or range of holes lies a *register* or *slide* R R, made of mahogany or wainscot, a little thinner than the bearers, but exactly fitting the groove. It is pierced with holes corresponding with those in the sound board, Fig. 1555, and it is evident that by drawing the slide a little towards one end, all the holes of the sound board will be covered, and the row of pipes placed over them will receive no wind. In some convenient part of the slide is a small slit, which receives a strong iron pin fixed in the sound board, whereby the exact degree of motion is allowed the slide for shutting or opening the holes. The slip or groove in which the slide runs, and the slide itself, are polished with black-lead for the sake of smoothness of motion. The wind is apt to run along under the slide, and to blow into a different hole to that intended, consequently causing the wrong pipe to speak, or rather to squeak. This *running of the wind* may be prevented by cutting small grooves in the top of the sound board, running in a zigzag line between the holes, as shown at S S, Fig. 1557: these channels conduct the superfluous wind out at the end of the slip, and thus remedy the evil.

Over the bearers and slides lie the *upper* or *stock boards*, S S B, Fig. 1555, in which the pipes are planted in holes bored for the purpose, corresponding of course with the holes in the sliders and sound board. The upper part of the feet of the pipes is supported by *racks* or thin boards R R mounted on small pillars. The upper boards are screwed to the bearers as closely as possible, with only just sufficient space to allow the registers to slide. In the case, however, of the larger stops, the pipes occupy so much space that they cannot stand immediately over the grooves which supply them with air: they are planted in any convenient positions within or even outside the case, and wind is conveyed to them by means of grooves cut in the upper board leading from the holes which would otherwise be occupied by the pipe, to within an inch or so of the place where the pipe actually stands: the groove is then discontinued and a hole is bored. When all the grooves are cut in the upper board, the surface is covered with parchment, which thus converts the open grooves into closed channels for the passage of the wind, which channels are open only at the hole on the under side, communicating with the sound board through the slider, and at the other hole into which the foot of the pipe is inserted.

The connexion between the finger key and the pipe will be more clearly understood by referring to Fig. 1558, in which f is the finger key moving on a centre pin c; r a small rod of wood called a *sticker*, the lower end of which rests on the distant end of the finger key: the upper end of the sticker is attached by a pin to the end of the lever l l, which moves on a centre at c'. To the opposite extremity of

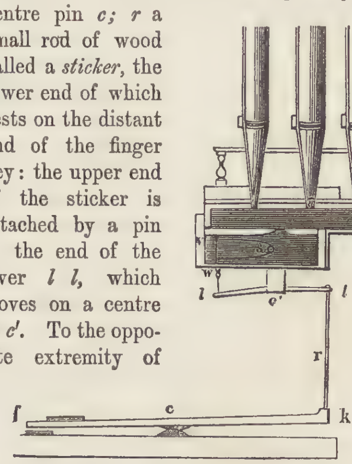


Fig. 1558.

this lever is attached a wire w, which passes air-tight through a brass plate at the bottom of the sound board, and the upper end of the wire is attached to the valve at v. Now when the finger key is pressed down, the opposite end of the key raises the sticker, which in its turn raises the end of the lever l, and lowers the opposite end, which draws down the valve v by the wire w. When the finger of the performer is removed the spring s closes the valve, and causes the lever, sticker, and key, aided, however, by their own weight, to fall into their original position.

The above arrangement, however, supposes the finger key to be opposite to the valve intended to be opened, a condition which evidently cannot apply to by far the larger number of pipes; for the key board is not more than 3 feet in width, even in the largest organ, while the sound board extends along nearly the whole width of the front. By means of a little more machinery the finger key is easily connected with the valve which it is intended to open. In Fig. 1559, $f\,f$ are the finger keys, $s\,s$ the sticker, and $l\,l$ the levers, as before; $r\,r'$ $r\,r'$ are rollers moving on their axes; W rods or wires attached to the ends of levers and to arms in the rollers towards the ends r; W$'$ W$'$ are wires from the valves V V, attached to the arms on the same side of the rollers towards their distant ends r'. It will be seen by this arrangement that by pressing the finger keys the valves will be opened as before.

In the large organ exhibited by Mr. Willis in the Great Exhibition, various ingenious mechanical novelties were introduced, among which may be mentioned the valve for admitting wind to the pipes in the pedal organ. It is formed by covering the aperture with a piece of leather fixed at one end, and attached at the other end to a wooden roller. When this roller is moved by a wire attached to the pedal key, it wraps

the leather round it and thus uncovers the opening; when the key is released, a spring brings the roller back, and by unrolling the leather again covers the aperture.

The key movement, represented in Fig. 1559, is called the *long* movement, because it may be extended to an almost indefinite length. It was used

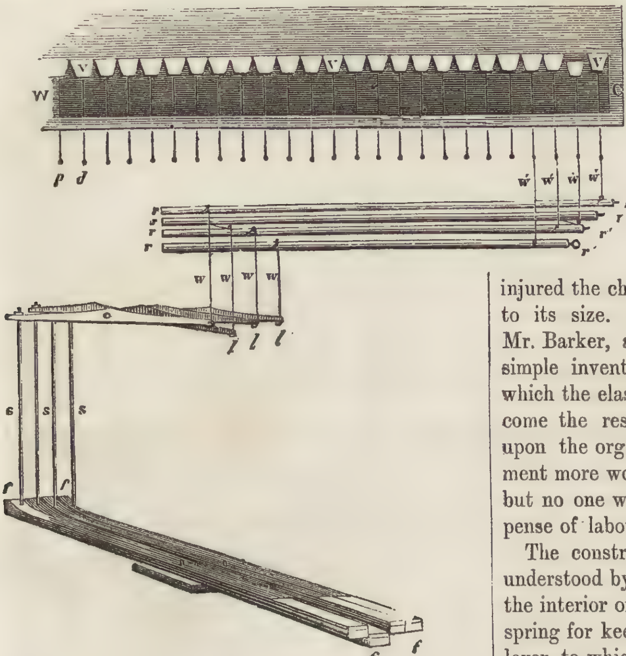


Fig. 1559.

for the organ at the commemoration of Handel in Westminster Abbey, when the keys were 23 feet from the organ, and 19 feet below the level of the common key frames. The construction will be assisted by observing the common method of hanging bells, the trackers in the organ being of wood instead of wire. In the organ at S. Alessandro in Colonna, at Bergamo, built by Serassi in 1782, there are about 100 stops, and 4 rows of keys: the first and second belong to the great organ and choir organ: the third is connected by mechanism, which passes underground to a distance of 115 feet, with a third great organ in another part of the church directly opposite the first. Notwithstanding the distance from the keys, the third organ obeys them as readily as the first. In Roman Catholic countries all the claviers are frequently fixed in a detached upright console, so that the player sits with his back turned to the instrument, thus enabling him to watch the service of the church and introduce the proper music at the proper times.

The organ, as usually constructed, requires not only consummate skill on the part of the performer, but also considerable strength both of hand and foot. It is stated that the organist at Haarlem is obliged to strip like a blacksmith for his usual hour's performance, and that at the end of it he retires covered with perspiration. Besides this, the expenditure of wind being very unequal, varying from a few hundreds to many thousand cubic feet per second, very different degrees of elastic force are produced in the air. The more elastic the air, the more readily the pipes speak, and the purer is the tone. When the expenditure of wind is small, the elasticity is greater than when it is large, and the pressure of highly elastic air against the valves renders them more difficult to open than when the air is only moderately compressed. The difficulty of opening the valves under strong pressure was attempted to be remedied by diminishing the quantity of wind or the dimensions of the larger pipes, by making the openings for the valves smaller, and bringing fewer stops into play at one time. These contrivances, however, injured the character of the organ, and put a limit to its size. At length a remedy was found by Mr. Barker, a native of Bath, in the beautiful and simple invention known as the *pneumatic lever*, in which the elasticity of the air itself is made to overcome the resistances which were formerly thrown upon the organist. It is true that in this arrangement more work is thrown upon the bellows-blower; but no one would object to relieve skill at the expense of labour.

The construction of the pneumatic lever will be understood by referring to Fig. 1560, in which W C is the interior of the wind-chest; *v* the valve, and *s* the spring for keeping it closed; *p d* the pull-down; *l* a lever, to which is attached the rod *r* connected with the finger-key apparatus. Through the valve *v* passes a screw wire *w*, terminating in a ring at the lower part, and furnished with a small button of leather at the top. C is the wind-channel, closed below by a skin of leather or parchment, as already explained. The top is partly closed by a small pair of bellows B, the bottom of which communicates by a slit with the

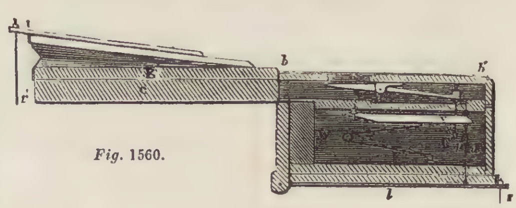


Fig. 1560.

channel C. The other portion of the top of the wind-chest is closed by a board *b b'*, fitting into grooves, so that by drawing forward the part *b'* it can be withdrawn together with the swing valve attached to it below. This valve *v'* moves upon a pin attached to a saddle-piece *p*. On the tail of the valve is a small leaden counterweight *c*, which causes the valve to close the opening *o* when the supporting button at the end of the wire *w* is drawn down. In its ordinary position this valve is kept half open by means of this button. The bellows B has a projecting piece or tail *t*, to which is attached a rod *r'* communicating with the valves, coupling-movements, &c. which have to be moved.

The action is as follows: on depressing the finger-key which corresponds with the rod *r*, the lever *l* opens the valve *v* by means of the pull-down *p d*; at the same time the valve *v′*, not being supported by the button on *w*, falls upon the opening *o* and closes it. The air, strongly condensed in the wind-chest, rushes with great force into the channel C, and also into the bellows B, which are instantly inflated, and in rising overcome all the resistances which act on the rod *r′*. So long as the finger continues to press down the key, the air remains compressed in the bellows, and keeps them inflated; but as soon as the finger is removed, the valve *v* rises, and by means of the wire *w* presses the tail of the valve *v′*, which it half opens, and allows the condensed air to escape from C and B. The rapidity and precision with which all this is done are surprising: the bellows B rise and fall simultaneously with the motion of the finger-key, and the notes may be repeated with equal facility. The bellows B vary in size with the resistances to be overcome, but they are usually not more than a few inches in length and breadth. The pneumatic lever is supplied with air by a special bellows, which compresses it much more highly than the ordinary bellows which supply the pipes with wind.

Our limits will not allow us to detail various other mechanical contrivances which add to the efficiency of the organ; but a few may be just alluded to. By means of certain movements called *couplers*, made to act by draw-stops in front of the instrument, or by pedals, different sets of *keys* may be made to act together, so as to give additional power and variety. Thus the great organ may be coupled with the choir and the swell, or the key-boards may be united in pairs; or one key may be coupled with another, so as to sound its octave above or below. In Italy this kind of mechanism is called the *terzo mano*, or third hand.

We must also notice Mr. Bishop's admirable *composition pedals* for opening and shutting the stops by the foot, so that the hands need not be removed from the key-board. A series of pedals is arranged above the usual pedals, and to each pedal corresponds a certain combination or composition of stops, so that on pressing down the pedal, the required stops are drawn, and at the same time push in those which do not belong to its own combination.

Mr. Bishop is also the inventor of an *anti-concussion apparatus*, for preventing the pulsation or concussion of air in the wind-chest when a large number of pipes are suddenly made to cease speaking, and a few only held on. It consists of a small reservoir connected with the wind-trunk, held down by a spring of sufficient force to balance the ordinary pressure of wind. When the rush of wind to a large number of pipes is suddenly checked, this spring yields, and allows the escape of a portion of the condensed air, which would otherwise expend its force on the pipes which are speaking.

We cannot conclude this imperfect notice without referring to the *barrel* organ. This contains the parts of finger organs, with the addition of a cylinder or barrel revolving on pivots instead of the key-board. The tunes to be played are set on the surface of the barrel by means of wires, pins, and staples. These, by the equable revolution of the barrel, act upon levers, and give admission to the wind from the bellows to the pipes. The same action of the hand which turns the barrel, supplies wind by giving motion to the bellows. Fig. 1561 is the section of a small barrel organ, in which C is the barrel or cylinder, on the axis of which is fixed a toothed wheel W, in the teeth of which a screw on the axle A, turned by the handle H, works, and thus causes the barrel to revolve. The pegs,

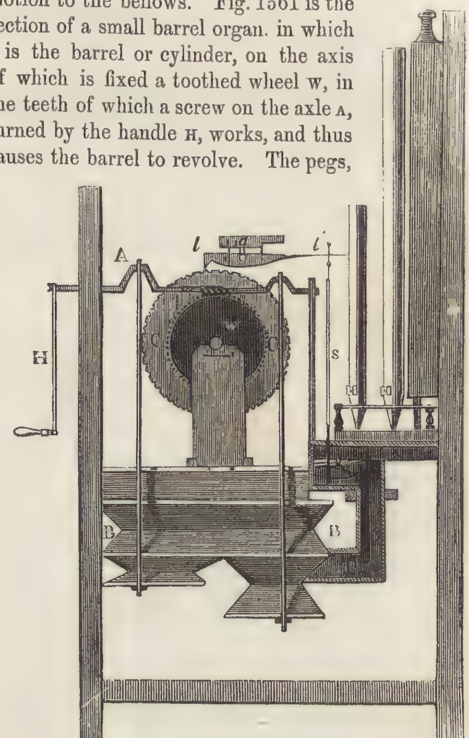


Fig. 1561.

&c. are shown on the surface of the barrel, one of which keeps up the lever *l l′*, which moves on the axis *a*. The end *l′* of the lever pushes down the sticker *s*, which, by a wire passing into the wind-chest, opens the valve *v*. "Suppose on this barrel an air of 32 bars were to be set, and conceive the circumference of the circle divided into so many equal parts, these parts will represent the bars or measures of the air; and being occupied with the due proportion of pegs and blanks under the proper levers, will, by the turning of the cylinder, make the proper pipes speak at their right times. As the levers for opening the valves are at a considerable distance apart, and the pegs occupy very little space, there is room for several airs being set on the same barrel. This being pushed a little way towards one side, till the pegs of another tune are brought under the levers, is there fixed by means of a sliding bolt, which falls into a notch in a piece of brass fixed to the frame in which the barrel runs. When pieces of music are to be set on a barrel longer than one revolution could afford space for, the end of the axle of the cylinder is formed into a screw, which works on a fixed pin, and consequently draws the barrel horizontally while turning round its axis. The pegs are

then disposed in spiral lines round the surface, so that those of the first revolution are clear of the levers when those of the second come to them. Thus as many revolutions are obtained as are necessary."

ORPIMENT. See ARSENIC.

OSCILLATION. See CENTRE.

OSIER. See BASKET.

OSMIUM (Os 100), a rare metal contained in the ore of platinum, and named from the acrid poisonous smell (ὀσμή, odour) of its peroxide. The metal, in its most compact state, has a bluish-white colour: it is somewhat flexible in thin plates, but is easily reduced to powder. Its sp. gr. is 10. It is neither fusible nor volatile. When heated to redness it burns, and forms the peroxide or *Osmic acid*, OsO_4, which is volatile. There are 4 other compounds with oxygen, viz. OsO, the *protoxide;* Os_2O_3, the *sesquioxide;* OsO_2, the *binoxide*, and OsO_3, *Osmious acid;* the last exists only in combination with alkaline bases. Osmium has not been applied to any use in the arts.

OXALIC ACID ($C_2O_3, HO+2HO$) occurs ready formed in several plants in combination with potash as an acid salt, or with lime, such as the *Oxalis acetosella* or *wood sorrel*, the *Rumex acetosa* or *common sorrel*, the varieties of *rhubarb* and other plants. In some parts of Suabia it is prepared from the *rumex:* the plant is piled up in a rude kind of lever press, and the juice expressed: what remains in the press is sprinkled with water, and pressed a second time. The juice thus obtained is clarified by being mixed up with a white argillaceous earth, and the clear liquor being decanted off is crystallized by evaporation. The crystals consist of binoxalate and quadroxalate of potash, known in commerce as *salt of sorrel.* The oxalic acid is obtained by adding acetate of lead to a solution of the salt of sorrel: oxalate of lead is thrown down, which is decomposed by the proper quantity of sulphuric acid: the liquor, on being evaporated, yields crystals of oxalic acid.

The commercial demand for oxalic acid is chiefly supplied by forming it artificially by the action of nitric acid on sugar, treacle, and dextrine. 1 part of sugar is heated gently in a retort with 5 parts nitric acid of sp. gr. 1·42 diluted with twice its weight of water: the acid is rapidly decomposed with copious red fumes, and the sugar is oxidized. As the action slackens heat is again applied, and the liquid concentrated by distilling off the superfluous nitric acid until it deposits crystals on cooling. "These are drained, redissolved in a small quantity of hot water, and the solution set aside to cool. The acid separates from a hot solution in colourless transparent crystals derived from an oblique rhombic prism, which contain 3 equivalents of water, 1 of these being basic and inseparable, except by substitution; the other 2 may be expelled by a very gentle heat, the crystals crumbling down to a soft white powder, which may be sublimed in great measure without decomposition. The crystallized acid, on the contrary, is decomposed by a high temperature into carbonic and formic acids, and carbonic oxide, without solid residue."—*Fownes.*

In the manufacture of oxalic acid on the large scale, use is also made of the saccharine substance formed by the action of sulphuric acid on potato or other starch (as in Nyren's process). For this purpose, the potatoes are well washed, and reduced to a fine pulp by rasping and grinding. The pulp is then washed a few times by well stirring it in water: and being allowed to subside, the water is run off. The pulp is next transferred to a vessel lined with lead, with as much water as will allow of the mixture being boiled freely, by means of steam pipes of lead. To the mixture of pulp and water, about 2 per cent. by weight (of the potatoes employed) of sulphuric acid is stirred in: this is at the rate of from 8 to 10 per cent. of acid on the quantity of farina contained in the potatoes. The whole is boiled for some hours, until the pulp of the potatoes is converted into saccharine matter. The completion of the process is ascertained by a drop of tincture of iodine to a small quantity of boiling liquor placed on the surface of a piece of glass: if any farina remain unconverted a purple colour will be produced. The saccharine product thus obtained is filtered through a horse-hair cloth, and carefully evaporated, until a gallon of it weighs about 14 or $14\frac{1}{2}$ lbs. It is now in a proper condition to be employed in the manufacture of oxalic acid, by the application of nitric acid as when sugar or treacle is used: a portion of the oxygen of the nitric acid is substituted for the hydrogen of the sugar, oxalic acid being formed, and binoxide of nitrogen evolved from the liquor.

Horse-chestnuts deprived of their outer shells may be used instead of potatoes in this manufacture: they are treated in the same way. Instead of the sulphuric acid, the same proportion of diastase may be used; in which case, the liquor is made of the required strength at once, and filtration and evaporation are not required.

The apparatus used in the conversion of the saccharine matter into oxalic acid consists usually of earthenware jars, of about 2 gallons' capacity, which, when charged with nitric acid and saccharine matter, are placed in water baths capable of holding 100 or more of these jars. These baths are of brick, lined with lead, and are heated by steam coils of lead. Instead of jars, vessels of lead, or of wood lined with lead may be used: 8 feet square and 3 feet deep is a good size, and a coil of 48 feet of 1 inch pipe gives the required heat—about 125° Fahr. The strength of the nitric acid should be from 1·200 to 1·270. While the operation is in progress, the active evolution of gas with the appearance of red fumes, and a peculiar smell, are signs of good working condition. The judicious addition of sulphuric acid increases the product of oxalic acid.

The product of oxalic acid from sugar has been understated by chemical writers, probably from the fact, that by boiling the sugar with strong nitric acid, a large portion of oxalic acid becomes converted as soon as formed into carbonic acid, and is lost. Thus, it is stated, that 100 lbs. of good sugar yield 50 or 60 lbs. of oxalic acid; whereas the manufacturer will obtain

from 125 to 130 lbs. from that quantity. 100 lbs. of average treacle yield 105 to 110 lbs. of oxalic acid.

The mother liquor having been poured off, the crystals of oxalic acid are thrown on drainers and washed. The mother liquor is treated with a fresh supply of nitric acid and treacle for another operation.

Other methods have been described for the manufacture of oxalic acid,[1] but the low prices of treacle and sugar are in favour of their direct use in this manufacture. Methods have also been contrived for employing the evolved vapours in the manufacture of nitric acid. For example, in Messrs. McDougall and Rawson's patent process, a series of vessels containing water are used, into the first of which the nitrous gas or fumes are passed through a tube dipping below the surface: air is also admitted, which mixes with the gas bubbling up through the water. Attached to the last vessel of the series is a pneumatic apparatus, by means of which the mixture of nitrous gas and air is drawn through this series of vessels, each containing a tube dipping into the liquid, and another tube attached to its top to connect it with the next vessel. The nitrous gas thus passing alternately into air and water becomes converted into nitric acid.

Ecarnot has patented a process for recovering the nitric acid: the regenerating vessels are filled with a porous substance such as pumice-stone; oxygen is supplied by a blowing machine, and a flow of steam is brought from a boiler. In this, as in Jullion's process, the following is the theory of action:—The oxides of nitrogen evolved from the liquor in the decomposing vessel coming in contact with oxygen are converted into hyponitrous and nitrous acids, which, on being mingled with steam, are decomposed into nitric acid, and binoxide of nitrogen. The use of steam may be obviated by using heated air or oxygen in the decomposing vessels, in which case the moisture will be furnished from the liquor, and the amount of mother liquor be diminished. The compounds thus formed, when passed through suitable condensers, will, if the supply of air or of oxygen has been in excess, be all or nearly all condensed into nitric acid.

The crystals of oxalic acid are soluble in 8 parts of water at 60°, and in their own weight or less of hot water. The solution is intensely sour and highly poisonous. Many accidents have occurred from the resemblance of the crystals of oxalic acid to those of sulphate of magnesia (Epsom salts), which has led to the careless dispensing of the one for the other. The intense sourness of oxalic acid, and the saline bitterness of Epsom salts, readily distinguish them. The remedies in cases of poisoning with the acid, are chalk or whiting, magnesia or its carbonate, or copious draughts of soap and water. One of these should be immediately resorted to.

The chief demand for oxalic acid is in calico-printing, where it is used as a discharger. [See CALICO PRINTING.] It is also employed by straw and Leghorn bonnet makers for the purpose of cleaning their wares. It is also used for cleaning boot-tops.

(1) See Pharmaceutical Journal for March, 1852.

The salts formed with oxalic acid are called *oxalates*. *Oxalate of potash* is sold under the name of "Essential Salt of Lemons" for the purpose of discharging iron-moulds from linen. The iron of the ink attaches itself firmly to the fibre of the linen: but as the iron is soluble in a solution of oxalic acid, it quits the linen and forms an oxalate of iron.

OXYGEN (O8). This important element is widely diffused throughout nature, but is never met with in a pure or isolated form. In the atmosphere it is mechanically mixed with nitrogen; in water it is chemically combined with hydrogen. It combines with nearly all the other simple substances, and forms with them an immense number of compounds. When we wish to obtain nitrogen for the purposes of experiment, all that is necessary is, to place in a confined portion of atmospheric air some substance such as will absorb the oxygen and leave the nitrogen free. The converse of this process cannot be adopted, since we are not acquainted with any substance capable of absorbing nitrogen and leaving the oxygen. There are, however, many solid bodies containing oxygen, which, on being subjected to a high temperature, evolve it in a gaseous form. Such are the red oxide of mercury [see MERCURY], the black oxide of manganese [see MANGANESE], or chlorate of potash. The first may be distilled in a glass tube, and requires only the moderate heat of a spirit-lamp: the second must be raised to a bright red heat in an iron gas bottle, or it may be mixed with sulphuric acid and distilled in a glass flask or retort: the third requires a high temperature in a retort made of glass containing no lead: but it is remarkable, that the presence of a little black oxide of manganese in powder, or of oxide of copper, allows the operation to be conducted much more rapidly, and at a much lower temperature. At between 450° and 500° the mixture begins to give off oxygen, being nearly 200° below the fusing point of the chlorate. A proportion of $\frac{1}{4}$ of oxide of manganese is quite effectual. The action of the metallic oxides has not been explained, except by vaguely referring it to *catalysis*, or that kind of combination or decomposition which takes place from the presence or *contact* of a body which is, as it were, the medium or cause of changes in which it does not itself necessarily partake. It seems natural to regard this example of it as a mere effect of heat, the particles of manganese or of copper acting as an assemblage of foci upon the powdered chlorate of potash with which they are in contact; but in such case, any powder would have the same effect provided it were not readily combustible in oxygen, and not liable to change in the presence of the potash salt. It appears, however, that sand, powdered glass, &c., has little or no effect.

Professor Miller, of King's College, London, has, at the request of the Editor, kindly undertaken a few experiments on this subject. The results are as follows:—When the chlorate of potash is mixed with peroxide of manganese, peroxide of iron, peroxide of lead, or oxide of copper, the gas is developed at least 100° below the fusing point of the salt. The metals, manganese, iron, lead, and copper, form (with the ex-

ception of the last) oxides of an acid character, which are very unstable and readily part with their excess of oxygen. Powdered glass and sand produce an extrication of gas after the salt has fused, but at a lower temperature than with the pure salt. Oxide of zinc produces no effect; nor does magnesia. These oxides are the only known oxides of the metals which yield them. The general conclusion appears to be, that metals which are capable of forming peroxides, readily decomposable by heat, favour the decomposition of chlorate of potash at a low temperature; while the oxides of those metals which are not capable of forming peroxides, do not favour the decomposition.

For the methods of collecting gases at the pneumatic trough, and for experimenting with them, we must refer to chemical works.

Pure oxygen gas is without taste, colour, or odour: it has not been reduced to the liquid form under great pressure and intense cold. It is a little heavier than its own bulk of atmospheric air, its sp. gr. being 1·1093. It is 16 times heavier than its own bulk of hydrogen. 100 cubic inches of it at mean temperature and pressure weigh 34·109 grains. It is evolved at the positive electrode or anode, and is therefore placed among the electro-negative bodies or anions. It is scarcely soluble in water, nor does it alter the colour of litmus or render lime-water turbid. It is the grand supporter of life (whence it is sometimes called *vital air*), and also of combustion; and in illustrating its powers as a supporter of combustion, the chemist displays some of his most striking and beautiful experiments. A match of wood, with only a spark of fire upon it, or a taper, with only a red-hot wick, on being plunged into this gas, bursts into brilliant flame. Sulphur, charcoal, phosphorus, iron wire, &c., on being ignited and plunged into this gas, burn vividly. See COMBUSTION—CANDLE—HEAT—FUEL.

The compounds formed by the direct union of oxygen with other bodies, are called *oxides*. Some of these are *alkaline* or *basic*, such as potash, soda, oxide of silver or of lead. Others have directly opposite properties, and are *acid*, such as sulphuric acid, phosphoric acid, &c.: they unite with the basic oxides and form salts. A third group is termed *neutral oxides*, from not readily entering into combination: black oxide of manganese is an example. See AFFINITY—ATOMIC THEORY.

Oxygen was discovered by Dr. Priestley in 1774, and about the same time by Scheele in Sweden and Lavoisier in France. The term oxygen was given to it by Lavoisier, from ὀξὺς, acid, and γεννάω, to produce, on the supposition that by combining with other bodies, such as sulphur, phosphorus, &c., it formed acids; but we have seen that it may produce alkalies or substances which are quite neutral. There are also acids which contain no oxygen. [See HYDROCHLORIC ACID.] The term *principle of acidity*, as applied to oxygen, has long been abandoned, for it is now admitted that the properties *sour, sweet, bitter*, &c., are not ultimate properties capable of being referred to any principle, but simply the result of new molecular arrangements which are capable of affecting differently our organs of taste. Thus the solutions of nitrate of silver and hyposulphite of soda have a nauseous bitter taste, but if they be mixed together they produce an intensely sweet taste. The word oxygen is too deeply rooted in scientific nomenclature to be safely removed, but it may be taken as a remarkable instance of an abiding word which changed its original meaning within a comparatively short period after its introduction.

PADDLE-WHEELS. See STEAM NAVIGATION.

PACKING-PRESS, a term sometimes applied to the hydrostatic press when used for packing goods. See HYDROSTATICS and HYDRODYNAMICS.

PAINTING. The mechanical processes concerned in painting, as a fine art, require so much skill, that a notice of them would be of little use to the general reader. ENAMEL PAINTING has been described under that head. HOUSE painting remains to be noticed. This is the art of applying to the interior and exterior of houses and other buildings a certain durable composition capable of preserving them from decay, of keeping walls dry by preventing the absorption of moisture, of rendering surfaces less liable to soil, and capable of being easily cleaned. The decorative effect is also not the least of the advantages of this art, provided the painter exercise it with taste, according to the principles developed by M. Chevreul [see LIGHT], and by Mr. Hay, himself a house-painter, in his treatise "on the Laws of harmonious Colouring, adapted to interior Decoration."

Paint is a kind of paste, made by grinding white-lead and linseed-oil. Other substances are used, such as colouring matters or *stainers*, as they are called, drying materials or *dryers*, &c.; but white-lead is the basis of all ordinary paints, and forms at least $\frac{9}{10}$ths of their composition. The laborious and unwholesome operation of grinding paints with a grinding-stone and muller, which was formerly done by the painter, is now performed by the manufacturing chemist on a large scale in paint mills, which resemble in many respects the mill described under *chocolate*. The linseed-oil is sometimes boiled, which gives it a greater facility in drying, but makes it thick, so that it is only fit for outdoor work. Spirits of turpentine, called *turps*, are also much used. Litharge and sugar of lead ground in oil into a thick paste, are used as dryers. Japanner's gold size is used for the same purpose. Ochre, Venetian red, lamp-black, Indian red, Turkey and English umber, terra de Sienna, red-lead, Prussian blue, orange red, chrome yellow, vermilion, and other pigments are used as stainers.

Surfaces are prepared for painting by means of sand-paper or pumice-stone, or by filling up with putty, for the purpose of getting rid of inequalities. Heads of nails are punched in, and stopped. Knots in the wood, which would bulge out, or leave a stain, are removed or cut out to the depth of $\frac{1}{4}$ inch, and pieces of the same wood inserted in their places, glued in hand-tight only, for if compressed with a hammer, they may afterwards swell and spoil the

surface. For ordinary work, knots are merely painted over with red lead and size.

In order to paint plaster, such as the walls of a room or hall, properly, five coats are required. If the plaster be not very absorbent, four will suffice. The first consists of white lead diluted with linseed oil to a thin consistency, with the addition of a small quantity of litharge to ensure the drying. If the plaster be *quick*, the oil is entirely absorbed, thereby hardening the plaster to the depth of $\frac{1}{8}$ inch. The second coat is also thin, in order that the plaster may be thoroughly saturated. This coat is only partially absorbed. The third coat is thicker, and contains a little turps, and some of the colouring pigment, so as to bring it near the tint required. The fourth coat is as thick as it can be used, equal parts of oil and turps being employed. The colour is used several shades darker than the finishing coat, and the dryer is sugar of lead. The coats must be laid on carefully and smoothly, each being rubbed lightly with sand-paper before the next is applied. The finishing or *flatting* coat, as it is termed, from its drying without gloss, is of pure white lead diluted with spirits of turpentine only, and is made a few shades lighter than the pattern, since it darkens in drying. A small portion of japanner's gold size is used as the dryer. The coat is applied as quickly as possible, since the turps evaporates in little more than a minute after being applied, leaving an indelible glossy surface. The time which is to be allowed between the application of the several coats, will depend on the weather, the quantity of dryer employed, and the state of the internal atmosphere. A few days should elapse between the putting on of the first two coats; a somewhat longer time before the third is put on. The last coat before the flatting should not be left more than two days, since much of the beauty and solidity of the work depend on the latter drying into and uniting with the former.

The absorption of moisture by the plaster of ceilings may be prevented by applying two coats of paint, and when dry and hard, a coat of *distemper* colour; that is, white lead ground in water and diluted with size made from parings of white leather and parchment. But in distemper painting it is very common to substitute whiting for white lead.

The painting of wood is similar to that of plaster, each coat being thicker and smoother than the previous one. In imitations of oak, marble, &c. there is a groundwork of four or five coats, care being taken that no brush-marks be left. The last coat, instead of being flatted, is composed of equal parts of oil and turps. The shades and grain of the wood are given by thin glazings of Vandyke brown, terra de Sienna, or umber, according to the kind of wood to be imitated. The colours are ground in water and mixed with small beer, the tenacity of which is sufficient to prevent its rubbing off by the application of the varnish which immediately follows. Wainscot is painted with a thick substance, to receive the impressions of an ivory or horn comb, with which the imitation of the grain is produced. The varnish is copal. Imitations of marbles, &c. depend more on the taste and cultivation of the painter than on mechanical skill; a remark which applies to ornamental painting in general.

The painter works with hog's-bristle brushes, of various sizes. In laying on the colour, the brush should be applied at right angles to the face of the work, the ends of the hairs only touching it. The paint is thus forced into the pores of the wood, and equally distributed; whereas, if the brush be applied obliquely, the paint will be left in thick masses where it is first applied.

The constant use of white lead renders painting an unhealthy art; and it soon becomes fatally so if those who exercise it are intemperate and uncleanly.[1] It is, however, satisfactory to reflect that the mechanic is every day becoming a wiser and a happier man; he prefers the coffee-shop and its instructive literature to the gin-palace or the beer-shop and its degrading results, and he has learned the important truth that his health is one of the talents entrusted to his charge, of which he will have one day to give account.

PALLADIUM, (Pd 54,) one of the metals found in the ore of platinum. It resembles platinum in colour, appearance, difficulty of fusion, and in being very malleable and ductile. Its density is 11·8. It is slowly attacked by nitric acid, but dissolves readily in aqua regia. There are two oxides, PdO and PdO_2. Several alloys of palladium are known. The alloy with iron is brittle, and in the proportion of 1 per cent. it is said to improve the quality of steel for certain cutting instruments. It destroys the colour of gold: 1 part fused with 6 of gold forms a white alloy, which, from its hardness and durability, was employed for the graduated part of the mural circle constructed by Troughton for the Greenwich Observatory. Electro-plating with palladium is in some cases useful, and is readily accomplished.

PALM OIL. See CANDLE—OILS AND FATS.

PANTOGRAPH, or PENTAGRAPH, an instrument for copying drawings, either on the same scale as the original, or in any given proportion to it, larger or smaller. It consists of 4 brass rulers, A B, B C, D E, and D F, Fig. 1562, the two longer of which, A B and B C, are connected together, and have a motion round a centre at B. The two shorter rulers are similarly connected at D, and with the longer rulers at E and F; and being equal in length to the portions B E

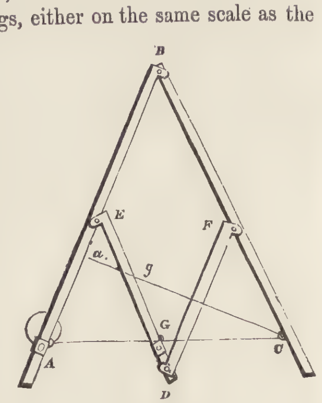


Fig. 1562.

(1) Attempts have been made to substitute white zinc for white lead in house-painting. The objections to its use are stated in our Introductory Essay, p. cxxxvi. For the mode of preparing white lead, see LEAD, and for white zinc, see ZINC.

and B F, form with them an accurate parallelogram, B F D E, in every position of the instrument. The instrument moves freely on ivory castors, which support it parallel to the paper. The arms A B and E D are graduated, and marked $\frac{1}{2}$, $\frac{1}{3}$, &c., and have each a sliding index, which can be fixed at any of the divisions by a clamping screw. The sliding indices have each a tube or sliding holder, with a pencil, a pen, or a blunt tracing-point. The tube at C contains the tracing-point; the tubes at G and A contain each a pencil. A small cup is sometimes placed over the tube, for containing sand or shot, in order to keep the pencil down upon the paper when the instrument is in use; but the pencil can at any moment be lifted off the paper by means of a silken cord which passes from the pencil round to the tracing-point at C, where the draughtsman is situated, so that he can raise the pencil from the paper while he passes the tracer from one part of the original to another, and he thus prevents false lines being made on the copy. At A is a flat leaden weight with a brass stem rising from it, which fits into any of the tubes. This weight has 3 or 4 fine points on its under surface, to prevent it from shifting on the paper; and under whichever tube it is placed, it forms a *fulcrum* round which the whole instrument moves.

Now, suppose the drawing is to be copied on the same scale as the original: the point C, where the tracer is situated, being permanent, the tubes A and G are slid along their respective bars until the points A G and C are all in a straight line, and the distance A G is equal to the distance C G, the tube G being exactly midway between A and C. The pencil is then fixed in the tube A, and the fulcrum is attached to the tube G, so that every part of the instrument revolves round G as a centre: the tracer C being moved by hand over the lines of the drawing, the pencil passes over the paper which is to receive the copy, and makes a line exactly similar and equal to that described by the tracer. For if the line B E be equal to D E, and D E equal to B F, then B E D F is a parallelogram, and will remain so however the 4 angles be altered. In our figure, B and D are acute angles, and E and F obtuse, and if the reverse were the case, the figure would still be a parallelogram. Nor need the 4 sides be of equal length; for if opposite sides are equal, that is, B E equal to D F, and D E equal to B F, the parallelogram will still be preserved.

If it be required to make the copy to a scale of half the original, the fulcrum is to be attached to the point A instead of G as before. The fulcrum and pencil have now changed places without any change having been made in the relative distances of A from G and of G from C. The consequence of the instrument turning round A as a fulcrum is, that the point G, where the pencil is, moves through only one-half of the space which the point C traverses, because the distance is only half as great from A as C is from A. Whatever length of line, therefore, the tracer C passes over, the pencil G will describe a line of half that length.

Let us now suppose the copy to be on a scale of $\frac{1}{4}$th the original, the arrangement will be as follows: C the tracer, *g* the pencil, and *a* the fulcrum, all being in a right line, the distance from *a* to C is 4 times as great as the distance from *a* to *g*; or the pencil is only $\frac{1}{4}$th as far distant from the fulcrum as the tracer is.

Any other proportion may be adopted, the adjustment being made according to this formula:—As the distance of the pencil from the fulcrum is to the distance of the tracer from the fulcrum, so is the size of the copy to that of the original.

In the French department of the Great Exhibition, M. Gavard's improved pantograph excited some attention in consequence of the delicate and difficult tracings performed by Madame Gavard by its means; such for example as a map of France, showing the depart-

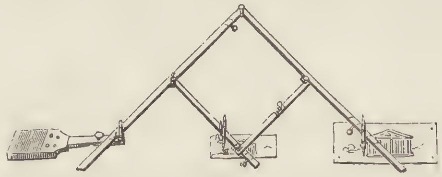


Fig. 1563.

ments, within a space of two inches square. In this instrument, represented in Fig. 1563, the improvements consist chiefly of a better arrangement of the fulcrum and larger size of the wheels, which add greatly to its steadiness.

PAPER, a thin flexible leaf usually white, artificially prepared from some vegetable substance, chiefly for writing or printing upon with ink. A species of paper was manufactured at a remote period in Egypt, from the *papyrus* or *paper-reed*, a plant growing freely on the banks of the Nile. A manufacture of paper from the bark of trees and other substances existed also in China, from a very early date; but among the nations of antiquity, before the introduction of paper, such substitutes were used as lead, brass, bricks, and stone, on which national edicts and records were written or engraved; or tablets of wood, wax, and ivory, skins of fishes, intestines of serpents, backs of tortoises, and the inner bark of trees for ordinary purposes. Indeed there are but few sorts of plants that have not been used for making paper and books, and hence have arisen the terms *biblos*, *codex*, *liber*, *folium*, *tabula*, *tillura*, *philura*, *scheda*, &c., which express the several parts of the plant which were written on. The use of these was discontinued in Europe after the invention of papyrus and parchment, but they are still used in other parts of the world. The two early kinds of manufacture above alluded to, must first be noticed, before we describe the later invention of making paper from cotton and linen rags, which in the greater part of the world has superseded all other methods of producing a material for writing on. The Egyptian papyrus was made by laying thin plates of bark, taken from the middle of the paper-rush, side by side, but close together, on a hard smooth table: other pieces of the same size and thinness were then laid across the first at right angles; the whole was

moistened with the water of the Nile, which was supposed to have some agglutinating property, (though this probably resided in the plant itself,) and pressure was then applied for a certain number of hours. Thus a sheet of paper was formed which required no other finishing than rubbing and polishing with a smooth stone, or with a solid glass hemisphere, and drying in the sun. This very simple process was rather a preparation of a natural paper, than a manufacture—properly so called. The process adopted by the Chinese comes more legitimately under that head. The small branches of a tree resembling our mulberry-tree, are cut by them in lengths of about 3 feet, and boiled in an alkaline ley for the sake of loosening the inner rind or bark, which is then peeled off, and dried for use. When a sufficient quantity of bark has been thus laid up, it is again softened in water for 3 or 4 days, and the outer parts are scraped off as useless; the rest is boiled in clear ley, which is kept strongly agitated all the time, until the bark has become tender, and separates into distinct fibres. It is then placed in a pan or sieve, and washed in a running stream, being at the same time worked with the hands until it becomes a delicate and soft pulp. For the finer sorts of paper the pulp receives a second washing in a linen bag; it is then spread out on a smooth table, and beaten with a wooden mallet, until it is extremely fine. Thus prepared, it is put into a tub with a slimy infusion of rice, and a root called oreni; then it is stirred until the ingredients are properly blended: it is next removed to a large vessel to admit of moulds being dipped into it. These moulds are made of bulrushes cut into narrow strips, and mounted in a frame; as the paper is moulded, the sheets are placed on a table covered with a double mat. The sheets are laid one on the other, with a small piece of reed between; and this, standing out a little way, serves afterwards to lift them up leaf by leaf. Every heap is covered with a board and weights to press out the water; on the following day, the sheets are lifted singly by means of the projecting reeds, and are placed on a plank to be dried in the sun. This paper is so delicate, that only one side can be written on, but the Chinese sometimes double the sheets, and glue them together so neatly, that they appear to be a single leaf.

This manufacture of the Chinese extended also to the making of sheets of paper from old rags, silk, hemp, and cotton, as early as the second century of the Christian era, and is supposed to have been the source whence the Arabs obtained their knowledge of paper-making. The latter people first introduced the valuable art of making paper from cotton into Europe, in the earlier half of the twelfth century, and established a paper manufactory in Spain. In 1150, the paper of Xativa, an ancient city of Valencia, had become famous, and was exported to the East and West. Notwithstanding its fame, this paper was of a coarse and inferior quality, so long as its manufacture was confined solely to the Arabs, in consequence of their employing only mortars, and hand or horse mills for reducing the cotton to a pulp, but when some Christian labourers obtained the management of the mills of Valencia and Toledo, the different processes of the manufacture were greatly improved. Cotton paper became general at the close of the twelfth and beginning of the thirteenth centuries, but in the fourteenth century, it was almost entirely superseded by paper made of hemp and linen rags. The paper made of cotton was found not to possess sufficient strength or solidity for many purposes; a very strong paper was therefore made of the above substances, not weakened by bleaching, according to the present mode, which, by removing the natural gum, impairs the strength of the vegetable fibre. Some of these old papers, having been well sized with gelatine, are said to possess their original qualities even to this day.

The manufacture of paper from linen rags became general in France, Italy, and Spain in the fourteenth century; the first German paper-mill was established at Nuremberg in 1390. English manuscripts on linen paper, date as early as 1340; but it is believed that the manufacture did not exist here until the end of the fifteenth century, when the *Bartolomœus* of Wynkyn de Worde appeared (1496), in which it is stated that paper of a superior kind was made for that work by John Tate, jun., at his mills in Stevenage, Hertfordshire. Probably the manufactory established by Tate was unsuccessful, for we hear no more of it, and in 1588 a German named Spielman, jeweller to Queen Elizabeth, established a paper-mill at Dartford.[1] Still for a lengthened period our supply of the finer kinds of paper was chiefly obtained from abroad. In 1770 the manufacture of fine paper was established at Maidstone, in Kent, by a celebrated maker, J. Whatman, who had worked as journeyman in some of the principal paper-mills on the Continent. Not long before this, *wove* moulds had been invented by Baskerville to obviate the usual roughness of *laid* paper, and these, attracting attention in France, led to the improvements which characterised the vellum paper of that period. Holland, too, contributed its share to the advancement of this manufacture, by inventing cylinders with steel blades for tearing the rags, and thus facilitating their conversion into pulp, which by the old method of stampers only, was a very slow and defective process.

In 1799 the first attempt to produce paper in an endless web was made in France by a workman in the employ of M. Didot. The invention was brought to England by M. Didot in 1801, and made the subject of patents, which in 1804 were assigned to the Messrs. Fourdrinier. Mr. Bryan Donkin, the engineer, carried out the desired plans, and produced, after intense application, a self-acting machine or working model, on an improved plan, of which he afterwards constructed many others for

(1) This mill is celebrated by a poet of that age in a work entitled, "A Description and Discourse of Paper, and the benefits it brings; with the setting forth of a paper-mill, built near Dartford, by a High-German, called Mr. Spilman, jeweller to the Queen. Lond. 1588. 4to."

home use and for exportation, which were perfectly successful in the manufacture of continuous paper. In the year 1851 Messrs. Donkin & Co. were constructing their 191st machine. In 1809 Mr. Dickinson, the celebrated paper-maker, invented another method of making endless paper, the highly ingenious details of which will be noticed hereafter. The Fourdrinier machines have been greatly improved by the inventions of Mr. T. B. Crompton, Mr. Brown, of Esk Mills, near Edinburgh, Mr. Ibotson, of Poyle, and other skilful manufacturers, English and foreign; so that at the present time, England, which was long dependent for its supplies on foreign countries, is not only able to produce an abundant supply for home use, but to export paper to a considerable amount.

At one time there were serious apprehensions that the supply of linen rags would fail, and various researches were entered upon by ingenious individuals to find substitutes. A book written in German by M. Schäffers so long ago as 1772,[1] contains 60 specimens of paper made of different materials. This ingenious person made paper from the bark of the willow, beech, aspen, hawthorn, lime, and mulberry; from the down of the asclepias, the catkins of black poplar, and the tendrils of the vine; from the stalks of nettle, mugwort, dyer's weed, thistle, bryony, burdock, clematis, willow-herb, and lily; from cabbage-stalks, fir-cones, moss, potatoes, wood-shavings, and saw-dust. Paper has been likewise made from straw, rice, hop-bine, liquorice-root, the stalks of the mallow, and the husks of Indian-corn. The fear of a failure of linen rags, and the consequent necessity for these experiments, were obviated by the discovery of chlorine. This powerful bleaching agent will restore many varieties of coloured linen to its original whiteness, as well as discoloured papers and manuscripts, so that the same substances may be used over and over again as a material for paper.

Section I.—Supply of Rags—Sorting—Washing—Grinding, and Bleaching.

The quality of the paper depends greatly on that of the linen worn in the country where it is made. Where that is coarse and brown, the rags and the paper made from them must be so too. In consequence of the enormous demand for paper in England, (62,960 tons' weight having paid duty in 1850,) the rags produced by a population of 27½ millions of inhabitants in Great Britain and Ireland, are by no means sufficient for the purpose. Large quantities of bagging, and other descriptions of linen, and cotton wrappers, old sails, cordage, and old navy stores, are employed in making paper: the waste of our cotton and other spinning mills also furnishes enormous quantities of material, which, mixed with rope, bagging, &c., produces strong and good paper for most purposes. In addition to these sources of supply, England imports from foreign countries upwards of 8,000 tons of material, consisting of old rags, old junk or ropes, or old fishing nets, for making paper or pasteboard. The following is the account of the imports in 1850:—

	Tons.
From Russia	859
Sweden	61
Norway	101
Denmark	206
Prussia	27
Germany, viz.	
Mecklenburg Schwerin	78
Hanover	23
Hanseatic Towns	4,449
Channel Islands	282
Italy:—	
Duchy of Tuscany	1,352
Papal Territories	305
Naples and Sicily	41
Austrian Territories	43
Malta	91
Egypt	23
British possessions in South Africa	27
——— East Indies	29
British Colonies in North America	25
United States of America	32
Brazil	18
Other parts	52
	8,124

The quality of the rags depends very much upon the state of civilization of the countries which produce them; the lower the degree of civilization, the more coarse and filthy are the rags. When the rags are received at the mill, they are sorted according to their respective qualities, for if rags of different qualities were ground at the same engine, the finest and best parts would be ground and carried off before the coarser were sufficiently reduced to make a pulp. In the sorting of rags intended for the manufacture of fine paper, hems and seams are kept apart, and coarse cloth separated from fine. Cloth made of tow should be separated from that made from linen, cloth of hemp from cloth of flax. Even the degree of wear should be attended to, for if rags comparatively new are mixed with those which are much worn, the one will be reduced to a good pulp, while the other is so completely ground up as to pass through the hair strainers; thus occasioning not only loss of material, but loss of beauty in the paper, for the smooth velvet softness of some papers may be produced by the finer particles thus carried off. The pulp produced from imperfectly sorted rags has a cloudy appearance, in consequence of some parts being less reduced than others, and the paper made from it is also cloudy, or thicker in some parts than in others, as is evident on holding a sheet up before the light. When it is necessary to mix different qualities of rags together to produce different qualities of paper, the rags should be ground separately, and the various pulps mixed together afterwards.

The rag-merchants sort rags into five qualities, known as Nos. 1, 2, 3, 4, and 5. No. 1 or *superfine*, consisting wholly of linen, is used for the finest writing papers. No. 5 is canvass, and may, after bleaching, be used for inferior printing papers. There is also *rag-bagging*, or the canvas sacks in which the rags are packed: also cotton coloured rags of all colours, but the blue is usually sorted out

(1) Sämmtliche Papierversuche von Jacob Christian Schäffers, Prediger zu Regenburg. *Regensburg*, 1772.

or making blue paper. Common papers are made from rag-bagging and cotton rags.

An operation sometimes required after unpacking the rags, is to put them into a *duster*, which is a cylinder 4 feet in diameter and 5 feet long, covered with wire net and enclosed in a tight box to confine the dust. A quantity of rags being put into this cylinder, it is made to rotate rapidly on its axis, and thus a good deal of dust is shaken out which might otherwise vitiate the air of the rag-cutting room.

The sorting is done by women and children in a large room: each sorter stands before a table frame, covered at the top with wire cloth, containing about nine meshes to the square inch. To this frame a long steel blade is attached, in a slanting position, as shown in Fig. 1564; and the sorter divides the rags

Fig. 1564. CUTTING RAGS.

into shreds by drawing them against the sharp edge of this knife; a good deal of the dust which is shaken out in this operation falls through the wire-cloth into a box beneath. The sections of rag are thrown into the compartments of the frame, according to their fineness. In importing rags some attention is paid to their quality by the foreign dealers, so that each bale is tolerably uniform. Formerly this was not the case, and in sorting a bale the woman had a piece of pasteboard hung from her girdle and extended on her knees, upon which with a long sharp knife she unripped seams and stitches and scraped off any adhering dirt. The rags were sorted according to their fineness, into the *superfine;* the *fine;* the *stitches* of the fine; the *middling;* the *seams* and *stitches* of the middling, and the *coarse*. These divisions are more or less observed at the present day. The very coarse parts are rejected or laid aside for making white-brown paper.

The sorted rags are washed with hot water and alkali, in an apparatus formed exactly on the principle of the *bucking keirs* or *puffers*, described under BLEACHING (Figs. 140, 141); or the washing is performed at one of the mills or engines about to be described.

The rags are ground into pulp in mills, now made sufficiently powerful to reduce the strongest and toughest rags. Formerly before the invention of mills, or when they were of much less power, it was customary to pile the rags in large stone vats, and leave them for a month or 6 weeks with frequent stirring and watering to ferment or rot, by which means the fibres became sufficiently loose to be reduced to pulp by pounding in wooden mortars with stampers. The arrangement of these mortars is thus described in an old treatise on the manufacture of paper:—"These mortars are cut out in a block of heart of oak, well seasoned, the cavity being of an oval figure about 18 inches broad, 30 inches long, and 18 or 20 in depth; the bottom concave and lined with an iron plate an inch thick, 8 inches broad, and 30 long, shaped inward like a mould for a salmon with the head and tail rounded. In the middle of the mortar is a cavity beneath the plate, and 4 or 5 grooves are cut, forming channels which lead to a hole cut from the bottom of the cavity quite through the block: it is covered by a piece of hair sieve fastened on the inside. This plate is grooved to make teeth, on which the teeth of the hammers act, to cut the rags in pieces. The use of the hair sieve is to prevent anything from going out except the foul water. Two hammers or pestles work side by side in each mortar, and are lifted alternately by the mill: they are sometimes made in the same manner as the stampers of an oil-mill, to lift perpendicularly. In other mills they are large hammers moving on a centre, like a fulling mill, and lifted by cogs upon the mill shaft in the same manner. The mortars are kept constantly supplied with fair water by little troughs, leading from a cistern which is kept full by small buckets affixed to the floats of the water wheel; these, when they have raised the water to the top, pour it out into the cistern in the same manner as the Persian wheel."

The mortars were superseded by what are called *engines*, a Dutch invention well adapted to the purpose. The engines are sometimes arranged in pairs on different levels, the bottom of one being higher than the top of the other, so that the contents of the higher engine may be let off into the lower. In the upper engine, called the *washer*, the rags are first worked coarsely with a stream of water running through them to wash and open their fibres: this reduces them to what is called *half stuff;* they are then let down into the *beating* engine to be ground into pulp fit for making paper. Each engine consists of a large wooden vat or cistern V V, Figs. 1565, 1566, of oblong figure on the outside, with the angles cut off: the inside, which is lined with lead, has straight sides and circular ends. Or the vat may be entirely formed of cast-iron. It is divided by a partition P P, also covered with lead. The cylinder C is firmly fixed to the spindle *s*, which extends across the engine and is put in motion by the pinion W, which engages other wheels set in motion by water or steam power. The cylinder is of wood, but is furnished with a number of teeth or cutters attached to its surface parallel with the axis, and projecting about an inch from it. Immediately below the cylinder is a block of wood B, also furnished with cutters, so that when the cylinder revolves its teeth pass very near those of the block, the distance between them being regulated by elevating or depressing the bear-

ings $l\,l$, on which the necks of the spindle $s\,s$ are supported. These bearings are made on two levers $l\,l$, which have tenons at their ends fitted into upright mortises made in stout beams $b\,b$, Fig. 1567, bolted to the sides of the engine. The levers $l\,l$ are movable at one end of each, the other ends being fitted to rise and fall on bolts in the beams $b\,b$, Fig. 1567, as centres. The front one of these levers, or

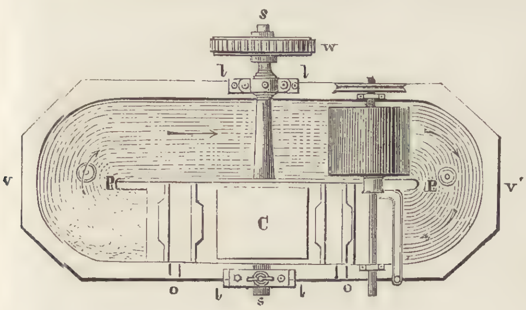


Fig. 1565.

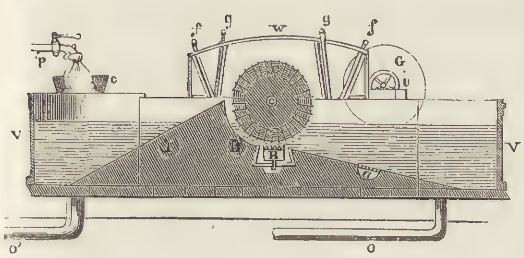


Fig. 1566.

that nearest the cylinder C, can be raised or lowered by turning the handle h of the screw, which acts in a nut n, fixed to the tenon of l, and rises through the top of the beam b, upon which the head of the screw takes its bearing. Two brasses let into the middle of the levers $l\,l$, act as bearings for the spindle of the engine: by turning the screw the cylinder is raised or lowered,

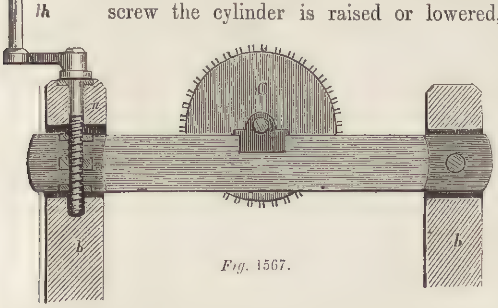


Fig. 1567.

and made to cut coarser or finer by enlarging or diminishing the space between the two sets of cutters. At one part of the vat is a breasting B′, made of boards and covered with sheet lead, curved to the form of the cylinder and nearly in contact with its teeth. An inclined plane I, passes from the bottom of the vat to the top of the breasting which terminates in the block B. The vat is supplied with water from the mill-dam by means of pumps worked by the water-wheel. The water is first discharged by the pipe P, Fig. 1566, into the cistern c, the supply being regulated by the cock in the pipe. A grating covered with a hair strainer is fixed across the cistern to prevent any solid impurity from passing into the vat; or the water may be strained through a flannel bag tied over the mouth of the pipe P, as shown in the figure. The vat being full of water and a quantity of rags put in, the cylinder is set in motion, the effect of which is to produce a regular current in the water in the direction of the arrows, by which the rags are drawn between the cutters of the cylinder and the teeth of the block; this cuts them to pieces: they are then thrown over the top of the breasting upon the inclined plane, down which they slowly slide and pass round the partition, and in about 20 minutes are again brought between the teeth of the cylinder and the block. The mode in which the rags are cut will be understood by considering that the teeth of the block are placed somewhat inclined to the axis of the cylinder, as shown in Fig. 1568, while the teeth of the cylinder are parallel to its axis, so that the cutting edges meet at a small angle and pass over each other something like the blade of a pair of shears, and the rags between

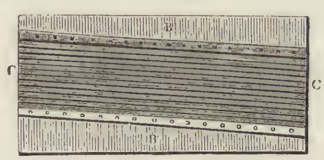


Fig. 1568.

them are cut up in a similar manner; and as they are brought many times under the action of the cutters, and must necessarily present their fibres each time in different directions, they are at length reduced to the condition of pulp. In some cases the cutters in the block B, instead of being straight, are bent to an angle in the middle, in which case they are called *elbow plates;* but in either case the edges of the cutters are curved so as to suit the curve of the cylinder. The plates or cutters are first screwed together and then fitted into a cavity cut out in the wooden block B, shown on a larger scale, Fig. 1569; the edges of the cutters are bevelled away on

Fig. 1569.

one side only. The block is fitted firmly into the bottom of the vat by being dove-tailed into it, and fastened by a wedge, on removing which, the block can easily be taken out for the purpose of sharpening the cutters. The cutters of the cylinder, Fig. 1570, are fixed in equidistant grooves, of which there are about 20: for the washer, each groove has 2 cutters or bars put into it; then

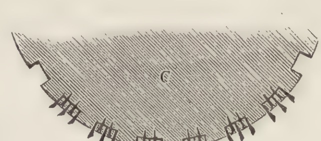


Fig. 1570.

a fillet of wood is driven in fast between them, and the fillets are kept fast by spikes driven into the solid wood of the cylinder. In each groove of the beater there are 3 bars and 2 fillets. In the beating engine the cylinder revolves quicker than the washer, the rate being from 120 to 150 times per

minute. The centrifugal force thus produced would project all the rags from the vat were it not for a wooden box or cover W, Fig. 1566, one side of which rests on the edge of the vat, and the other on the edge of the partition P P. At *ff* are wooden frames covered with hair or wire cloth, and immediately behind these the box is made with a bottom, and a ledge towards the cylinder. At *o o'*, Fig. 1565, are two openings or spouts which convey the foul water from the engine. As the cylinder revolves a large quantity of water and rags is thrown up against the sieves; the water passes through, runs into the trough at *o*, and escapes by the pipes. At *g g*, Fig. 1566, are grooves for two boards which cover the hair sieves, and prevent water from going through them when it is required to retain the water in the engine, as is the case in the beating engine, which, indeed, is not always furnished with these waste pipes, but with a drum or cylinder G of wire gauze, which is caused to revolve slowly by means of the upright spindle, as shown in Fig. 1571. As the water in the vat rises above a certain level it drains into this drum and escapes, but the meshes of the drum are too fine to allow any of the ground pulp to escape with the water. In a mill with 5 engines, 3 are beaters and 2 washers, the latter getting through their work more quickly than the former. The washing engine produces considerable vibration; for since it revolves 120 times per minute, and has 40 teeth, each of which passes by 12 or 14 teeth of the block at every revolution, it makes nearly 60,000 cuts per minute, each single cut being loud enough to produce a sound. The beater, with 60 teeth, and 20 to 24 cutters in the block, makes 180,000 cuts per minute, the effect of which is a low musical note or hum, audible at a distance from the mill. In the washing engine the rags are opened, their fibres separated, and the dirt removed. Any small solid impurities are collected in the trough *a*, Fig. 1566. When first put in, the rags are worked gently, the cylinder is raised some way above the block so as to rub rather than cut the rags; at the same time a copious stream of water is admitted; after 20 or 30 minutes, the cylinder is let down

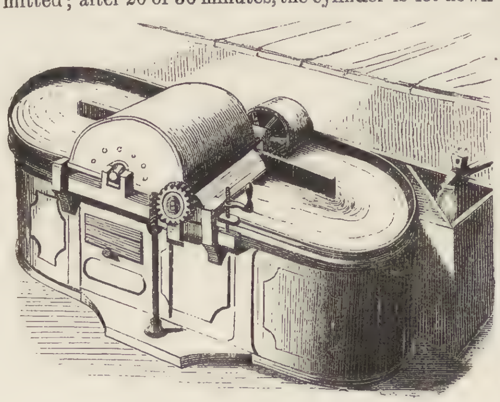


Fig. 1571. BEATING ENGINE.

so as to cut the rags, and the operation is at first so violent that the cylinder is often jerked or heaved up. After 3 or 4 hours the engine works steadily; the rags are cut up very small, and form what is called *half stuff:* this is let out into a basket, which retains it while the water flows off For some kinds of paper the half stuff is left to mellow, or ferment; but it is usual at this stage to *bleach* the stuff, which is done by a solution of chloride of lime in stone vats, or by using this solution instead of water in the engine at the last stage of the washing process, the slides *g g* being put down in the cover to prevent the loss of the solution. In the course of an hour the yellow rags or half stuff are converted into a snow white. This is then put into the beating engine, and in 4 or 5 hours it is ground into a fine pulp, a little water being let in from time to time, but none being allowed to escape. The quality of the water has considerable influence on that of the paper; the purest water is of course the best; water from chalky soils introduces lime into the pulp, and this forms a slight incrustation upon the moulds, which is washed off from time to time by vinegar.

In order to prevent common ink from running upon paper, size is introduced at a certain stage of the manufacture; but printing-ink being oily instead of watery, and moreover of greater consistence than common ink, is not so liable to run. Hence, for certain printing papers, the sizing is done in the beating engine towards the close of the operation. The size consists of finely pounded alum mixed with oil, about a pint and a half of the mixture being thrown into the engine at intervals during the last half-hour of the beating. The blue is produced by smalt, or artificial ultramarine.

SECTION II.—PAPER-MAKING BY HAND.

When the stuff is properly prepared, it is run out by the pipes O O', Fig. 1566, into the *stuff chest*, where the different kinds are mixed preparatory to moulding. From this chest it is transferred to vats or tubs, each about 5 feet in diameter and 2½ feet deep, provided at top with planks enclosed inwards to prevent the stuff from running over during the moulding. Across these planks is a board pierced with holes at one extremity, for supporting the mould. The stuff in the vat is kept at the proper temperature by a small grate placed in a hole lined with copper, at the side of the vat. The fuel is charcoal or coke, or the fire is entirely confined to the other side of the wall, a hole through it being made into the side of the vat. In this way smoke is prevented.

The paper is made into sheets by means of the *mould* and *deckle*, Figs. 1572, 1573. The mould is a square frame, or shallow box of mahogany, covered at the top with wire-cloth: it is an inch or an inch and a half wider

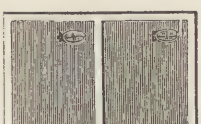


Fig. 1572.

Fig. 1573.

than the sheet of paper intended to be made upon it. The wire-cloth of the mould varies in fineness with

that of the paper and the nature of the stuff; it consists of a number of parallel wires stretched across a frame very near together, and tied fast through holes in the sides: a few other stronger wires are also placed across at right angles to the former: they are a considerable distance apart, and they are bound to the small wires at the points of intersection by means of fine wire. In several kinds of writing-paper the marks of the wires are evident from the paper being thinner in the parts where the pulp touched the wires. In what is called *wove* paper, there are no marks of the wires: these are avoided by weaving the wire in a loom into a wire-cloth, which is stretched over the frame of the mould, and being turned down over the sides is fastened by fine wire. The *water-mark* in paper is produced by wires bent into the shape of the required letter or device, and sewed to the surface of the mould;—it has the effect of making the paper thinner in those places. The old makers employed water-marks of an eccentric kind. Those of Caxton and other early printers were an ox-head and star, a collared dog's-head, a crown, a shield, a jug, &c. A fool's cap and bells employed as a water-mark, gave the name to *foolscap* paper; a postman's horn, such as was formerly in use, gave the name to *post* paper.

The *deckle* is a thin square mahogany frame, bound with brass at the angles: its outer dimensions correspond with the size of the mould, and its inner with that of the sheet of paper. The use of the frame is to retain the pulp upon the wire-cloth: it must be quite flat, so as to fit the cloth of the mould, otherwise the edges of the paper will be ragged and badly finished. When the deckle is placed upon the wire of the mould it forms a shallow sieve, in which the paper-maker takes up a quantity of the pulp suspended in water, and the water draining through, leaves the pulp in the form of a sheet upon the wire. The deckle is not fastened to the mould, but is held to it by the workman grasping the mould and deckle together in both hands at the opposite sides. When the sheet is moulded the deckle is removed, and the sheet is taken up from the wire by laying it on a piece of *felt* or woollen cloth. These felts prevent the sheets from coming together, and they also serve to imbibe a portion of the water from the damp and loosely cohering sheet.

In the moulding of paper there are usually three men employed, viz. the *dipper*, the *coucher*, and the *lifter*. The first, having filled the vat with pulp, mixes it up well with a pole, and afterwards with a perforated paddle; but, by a better arrangement, a mechanical stirrer is often used; this consists of a small wheel or *hog*, which being maintained in constant motion, keeps the pulp suspended. The stuff should float in close regular flakes; if not, it is a proof that the grinding has been badly done. The dipper stands in a niche made in the table which surrounds the vat, and holding the mould in both hands, with the deckle firmly pressed to it, he inclines it a little towards him, dips it into the vat, and brings it up again in a horizontal position. The superfluous part of the pulp flows over the sides; that which remains, and is according to the judgment of the dipper sufficient for a sheet of paper, is shaken gently from right to left, and up and down, until it is equally spread over the whole surface of the mould. This requires great skill and experience. As the water drains through the wire, the fibres of the pulp arrange themselves regularly on the wire-cloth. The mould is then placed on the edge of the vat, the deckle is taken off, and the mould slid along the board across the vat to the place where the sheet is to be *laid*, or taken off. The holes at the end of the board allow the water from the mould to drain into the vat. In the meantime the dipper places the deckle from the first mould upon a second mould, and proceeds to dip another sheet. The coucher takes up the first mould in his left hand, raises it gently, and places it in an inclined position against one or two small pins which are driven into the board on the edge of the vat; in this position it is left for a few seconds to complete the draining, while the coucher extends a felt on which he applies the mould in order to take off the sheet. This being done, he returns the mould to the dipper. In this way they proceed, alternately laying a sheet and a felt, until 6 quires of paper are made: this is called a *post*, and 2 men can make 20 posts a-day if the sheets are not very large. Whenever a post is completed it is put into a screw-press, which forces out a large quantity of water, hardens and consolidates the paper, and to a certain extent smooths down the risings and hollows made by the wires in laid paper. When a second post is ready the first is taken out by the lifter, who takes the sheets off the felt, and makes them up into a neat and compact pile without the felts; and when several piles are thus produced from several posts, they are put into a second or *wet-press*, as it is called. The sheets being pressed in contact with each other, a large quantity of water is got out, the sheets become considerably stronger, freckles or felt marks are removed. In proportion as the water is removed the fibres of the pulp interlace, and become felted together, so as to form a kind of felted cloth. When the paper is taken out of the press it is separated into small parcels of 7 or 8 sheets in each, for the purpose of drying. The drying is conducted in extensive lofts in the upper parts of the mill. The sheets are taken up upon a piece of wood, shaped like a T, and hung upon hair lines stretched across large horizontal wooden frames, called *tribbles*, and as these are filled they are lifted up between upright posts to the top of the room, and retained by pegs put into the posts; another frame is then filled, and put up in its turn, until the loft is filled. Air is admitted to the lofts by means of louvre boards. When sufficiently dry, the paper is taken down, and *sleeked*, *dressed*, and *shaken*, to get rid of dust, and to separate the pages. It is then laid in heaps in the warehouse preparatory to sizing. The size is made from the shreds and parings of leather and parchment; it is nicely filtered, and a little alum added. A number of sheets are then dipped into the size and separated so as to expose both surfaces of

each sheet: the sheets are taken out, turned over, and dipped a second time. About a dozen handfuls being thus dipped they are made into a pile, with a thin board or felt between every two handfuls, and pressed to get rid of superfluous size which flows back into the size vessel. The paper is again transferred to the lofts, and dried. This being complete, it is taken down, carried to a building called the *Saul*, (probably a corruption of the German *saal*, or the French *salle*, a hall, or large room,) where it is *examined*, *finished*, and *pressed*. The imperfect sheets (*retree*) are removed. The press called the *dry-press* is a powerful one, or the hydrostatic-press is used. After one pressing the heaps of paper are *parted*, that is, they are turned sheet by sheet, so as to expose new surfaces: the press is again used; then there is another parting, and so on, several times. The paper is next made into quires and reams, and once more pressed.

Connected with the sizing of papers, is the blueing; which is said to have originated in the suggestion of a paper-maker's wife, who thought that the practice of improving the *colour* of linen, while passing through the wash, by means of a blue-bag, might also be advantageously applied to paper. A blue-bag was accordingly suspended in the vat; and the effect proved to be so satisfactory, that it led to the introduction of the large and important class of blue writing papers. It was soon found that smalt gave a better colour than common stone-blue; and smalt continued to be used for many years; but when artificial ultramarine came to be manufactured at a very low cost, and in a great variety of tints, this beautiful colour gradually superseded smalt in the manufacture of writing paper. The introduction of ultramarine, however, led to some difficulty in sizing the paper. So long as smalt continued to be used, any amount of alum might be employed: and it was actually added to the size to preserve it from putrefaction. But as artificial ultramarine is bleached by alum, it is necessary to add this salt in very small proportions to the size for blue papers: and the consequence of this was, that the gelatine was no longer protected from the action of the air, which led to incipient decomposition; and, as happens in such cases, the putrefaction, once commenced, proceeded after the size was dried on the paper. This gave to the paper a most offensive smell: and whole bales of paper were returned to the maker as unsaleable.

Three remedies were tried for this serious defect:—1. The use of antiseptics, such as camphor, which would not decolorize the ultramarine. This method failed in consequence of the powerful antiseptics being poisonous, odorous, too volatile, or too costly. 2. Sulphurous acid was used, in order thoroughly to purify the *scrows* or clippings of skins, before they were converted into size. This plan was patented by Mr. Rattray, of Aberdeen, and adopted by several paper-makers. It answered its purpose admirably, but it was rather troublesome and somewhat costly, as the patentee had to be paid for his licence. The great value of sulphurous acid, consisted in its property of arresting putrefaction even after it had commenced. The scrows were even permitted to putrefy slightly, in order the more readily to get rid, by long maceration, of adhering hair, cellular tissue, and muscular fibre, &c. Putrefaction was then arrested by washing with an aqueous solution of sulphurous acid, and the size prepared from scrows treated in this way, dried quite sweet upon the paper. 3. The cost of the sulphurous acid process, led paper-makers to try the effect of improved methods of drying the paper after sizing; and in this they succeeded perfectly. All experience showed that if the size were quite free from taint when applied to the paper, and were quickly dried on it, putrefaction did not subsequently occur; if, however, decay had commenced, it could not be arrested by drying only. The method of drying which was found to succeed best, was to pass the paper over hollow skeleton cylinders, within each of which a fanner was kept rapidly revolving; the air of the room was heated artificially. The size is now made in the ordinary way.

After the paper is made up into reams it is again pressed, if possible, for 10 or 12 hours. After this, it is tied up in a wrapper with a label on it, which is filled up by the manufacturer and the excise officer respectively; the latter weighs the paper and stamps the wrapper, to indicate that the amount of duty has been charged to the maker.

Section III.—Paper-making by Machinery.

The slow and difficult process of moulding the separate sheets of paper by hand, has to a great extent been superseded by the introduction and gradual improvement of the very beautiful machine referred to in our introductory remarks. By means of this machine a process which, under the old system, occupied about 3 weeks, is now performed in as many minutes. Within this brief space of time, and the short distance of 30 or 40 feet, a continuous stream of fluid pulp is made into paper, dried, polished, and cut up into separate sheets ready for use. The paper thus produced is moderate in price, and for a large number of purposes superior in quality to that which was formerly made by hand. In fact, the machine-made papers can be produced of unlimited dimensions; they are of uniform thickness; they can be fabricated at any season of the year; they do not require to be sorted, trimmed, and hung up in the drying-house—operations which formerly led to so much waste, that about 1 sheet in every 5 was defective.

With the assistance of a steel engraving we will endeavour to give, first, a general idea of the common form of a paper-making machine, and then a more detailed notice. At one extremity of the building a large vat v, Fig. 1, is kept constantly supplied with pulp, or properly prepared stuff, which is prevented from subsiding by the revolution of the stirrer *s* upon its axis *a*. The stuff flows from the vat by a cock *c*, which is opened more or less, according to the thickness of the paper intended to be made. The stuff falls into the trough *t*, where it meets a large supply

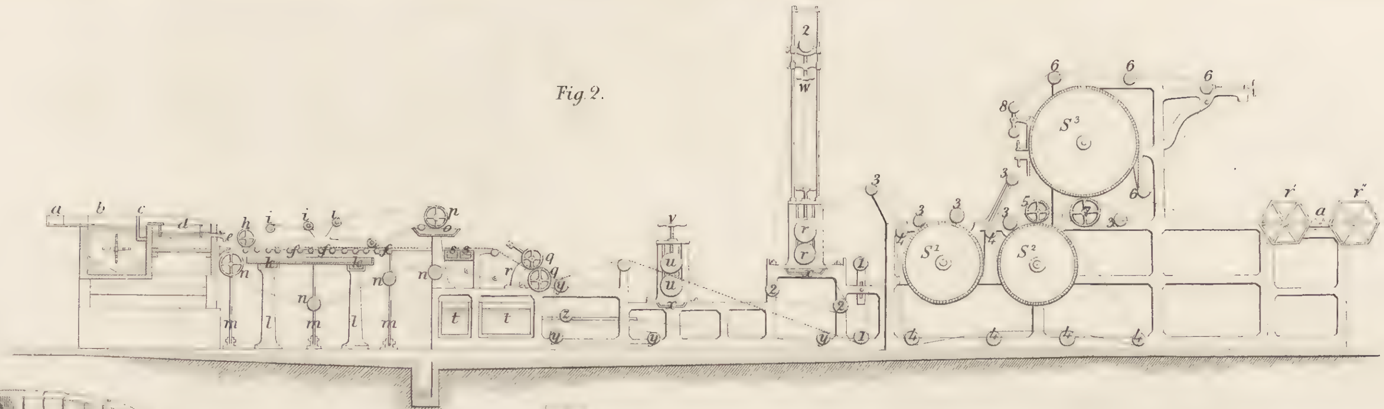


Fig. 2.

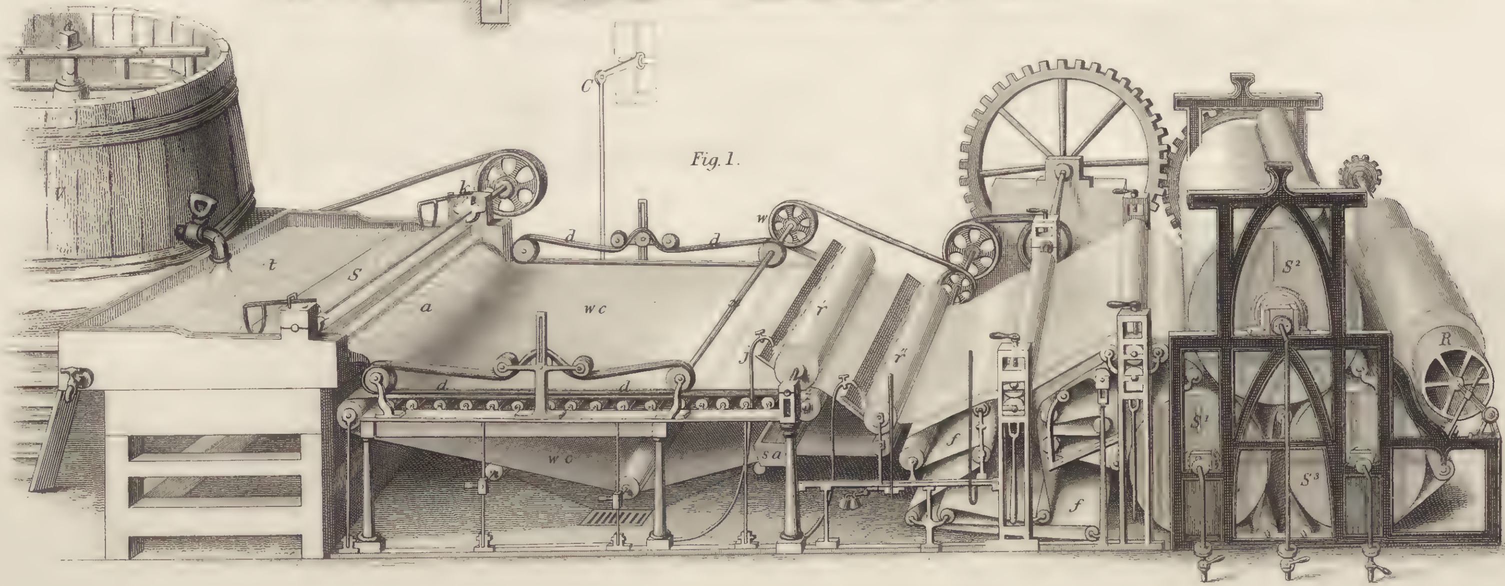


Fig. 1.

PAPER. PAPER MAKING MACHINE

of water, which has already passed through the web of the pulp, as will be explained hereafter. The stuff then passes through a strainer s, for the purpose of separating from the pulp knots, sand, and hard substances, which formerly caused so much damage to types and valuable wood engravings in the printing. Before the introduction of this strainer by M. Ibotson, the knots, &c. were scraped out of the paper after it was made in the salle, to the injury of its surface, thereby causing so much *retree* (damaged paper) to otherwise good and well-made paper. A common form of strainer is a rectangular trough of brass or gun-metal 5 or 6 feet long, 2 feet wide, and the sides about 4 inches deep. The bottom is formed of a number of heavy bars with smooth polished surfaces; they are each about an inch broad; they rest on a projecting ledge, and are firmly fixed in by wedges, so as to be almost in contact; the spaces between them allowing the fibres to pass lengthwise, but keeping back all knots and extraneous substances. A light shaft of brass or iron passes above the strainer, and above each end is a cam *k*, or notched wheel, working into the frame of the strainer, so that as the shaft revolves, the strainer is raised at every notch, and descends by its own weight, thus producing a continual jerking motion, making about 130 strokes per minute. As the knots accumulate, a man draws them towards him with a wooden rake, and shuts them off from the rest of the trough by means of a wooden hatch covered with felt, which he puts across the trough. Then scooping out the knots, &c., he takes out the sluice, and repeats the operation as often as required. The stuff thus strained, flows upon a leathern apron *a*, which conducts it to an endless wire-cloth *w c*, over which the web of paper is formed. This wire-cloth is about 28 feet in length, and varies from 48 to 100 inches in width, and has about 60 holes in the lineal, or 3,600 in the square inch: it is kept in motion upon a number of small copper rollers about 1½ inch in diameter, and the same distance apart. The rollers are supported by a frame, to which a slight but rapid lateral movement is imparted by means of a small crank c *c'*, and the vibration is made more or less rapid, according to the nature of the stuff. This shaking motion facilitates the escape of the water through the wire-cloth, and the felting together of the fibres of the pulp. The water holding a good deal of the flour of the pulp, is received in a large wooden vessel or *save-all* placed beneath the wire-cloth, and from this vessel it is raised by means of scoops, and poured into the trough *t*, where it dilutes the supply of stuff from the vat. The edges of the paper on the wire gauze are formed of belts, or deckles of linen and caoutchouc *d d;* they are half an inch thick, and 16 feet long, and are kept distended by the system of friction rollers represented in the engraving. Motion is given to them by the wheel *w* acting on the axis *x*, and they press with moderate force, not sufficient to prevent the free motion of the wire-cloth, but enough to prevent the pulp from flowing off laterally before the fibres have set. By the time the deckle-straps leave the wire-cloth, the stuff is no longer fluid, although much water continues to escape from it. The wire-cloth with the pulp upon it passes on until it comes to a couple of *wet-press cylinders r'*, as they are called, the lower of which is of metal, but covered with a jacket of felting or flannel; the upper one is of wood made hollow, and covered first with mahogany, and then with flannel. To prevent the paper from adhering, the surface of this upper roller is kept wet by a jet of water, *j*, running along a trough, as will be more particularly noticed in the description of Fig. 2. These cylinders give the gauze with the pulp upon it a slight pressure, which is repeated upon a second pair of wet-press rolls *r''* similar to the first. The paper pulp is then led on upon an endless felt or blanket, *f f*, which travels at exactly the same rate as the wire-cloth, otherwise the paper would be torn. The wire-cloth turns round under the wet-press cylinders to obtain a new supply of pulp, and is kept distended by copper friction rollers, which move by the friction of the cloth. The water which escapes from the wet-press rolls is received by the save-all *s a*. The endless felt conveys the web of paper, still in a very wet state, between cast-iron cylinders, where it undergoes a severe pressure, which gets rid of much of the remaining water, leaving the web sufficiently firm to be handled. The paper is passed between a second pair of press-rollers, which remove the mark of the felt from the under surface. It is then passed over the surface of the cylinders heated with steam, s^1 s^2 s^3; and when it has passed over about 30 lineal feet of heated surface, it is wound upon a reel R, ready for the cutting machine, or it passes at once to the cutting machine, as will be noticed hereafter.

We will now, with the assistance of Fig. 2 of the steel engraving, describe this machine with greater minuteness. Commencing at the left-hand extremity of the machine, we have a vat at *b*, kept well supplied with pulp, which is held in suspension by the motion of a small agitator or hog. The pulp is further diluted in this vat by the water which has already passed through the wire gauze into the save-all at *k*, from which it is raised by a Persian wheel, and poured into the vat *b* by the trough *a*. The bottom of the vat *b* is arranged so that a jet of steam may pass through it, and raise the temperature, as is sometimes required for coarse pulps. At *c* is a partition, which forces the pulp to pass near the agitator, so as to be properly suspended in the water before it flows upon the strainer *d*. After having been freed from knots by passing through the strainer, the purified pulp escapes by a cock, and, falling upon a leathern apron at *e*, is conducted to the wire-cloth. The water drains through the wire-cloth, and the fibres of the pulp completely cover and conceal it. In order, therefore, to distinguish the paper, it is marked in our figure with a dotted line, while the wire-cloth, and afterwards the blankets, are distinguished by a continuous line. The wire-cloth, which is kept distended by the friction rollers *n n*, extends from *e n* to *q q*, and where it first receives the pulp; it is sup-

ported in a horizontal position upon hollow copper rollers *f f;* and here the width of the paper is regulated by the deckle strap, which is moved along the edge of the wire-cloth, in flat contact with it, and constantly returning, by means of the system of pulleys *p i h*, supported by the frame *s*. The supporting arms of some of these pulleys admit of being adjusted so as to regulate the tension of the strap. There is, of course, a similar system on the other side of the machine. A jet of water, supplied by the cistern *o*, constantly plays upon the deckle strap, for the purpose of removing the fibres of pulp which it takes up from the wire-cloth.

The wire-cloth rollers *f f*, the frame *s*, and the friction rollers *n n*, are supported by the iron rods *m m*. The whole system has a rapid to and fro motion imparted to it by means of a short crank connected with the movable supports *m m*. This motion serves to distribute the pulp evenly over the wire-cloth, and to facilitate the draining through of the water; this is received in the save-all *k k*, which is raised on the firm supports *l l*. The water from the save-all flows by a pipe into a vessel in which the scoop buckets of

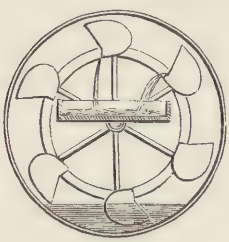


Fig. 1574.

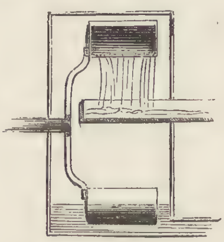


Fig. 1575.

a Persian wheel, shown in two views, Figs. 1574, 1575, dip in succession as the wheel revolves, and raise the water to the trough placed just above the axis of the wheel; this trough conveys the water to *a*, as already noticed. As the wire-cloth advances

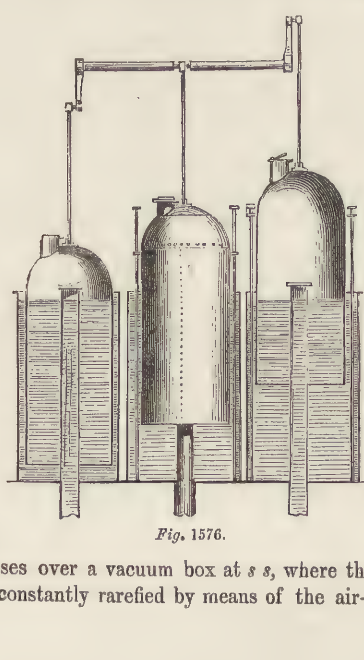


Fig. 1576.

it passes over a vacuum box at *s s*, where the air is kept constantly rarefied by means of the air-pumps, Fig. 1576, which communicate therewith by the three vertical pipes covered at the top, with valves opening upwards. The action of this pump will be seen at a glance: three bell-shaped vessels moving vertically by means of guide-rods in tanks of water over the vertical pipes, are attached by cranks to a horizontal axis, the revolution of which causes the vessels to move up and down. During the upward motion of one of these vessels the air within it becomes rarefied, and the consequence is, that air rushes from the vacuum box, *s s*, along the vertical pipe, forcing open the valve at the top in order to restore equilibrium within the vessel. During the downward motion the valve at the top of the vertical pipe is closed, and a valve at the top of the bell vessel opened whereby the air is discharged preparatory to a fresh ascent, when the action is repeated as before. As there are three of these bell-shaped vessels, the cranks for which are set at right angles to each other on the same axis, one of these vessels is always in full action; the consequence is, that tolerably dry air is constantly streaming through the pulp and wire-cloth into the box *s s*, whereby a large quantity of water is drained off, and the pulp becomes consolidated and better prepared for being transferred from the wire-cloth to the blanket. Should, however, any accident occur to prevent the progress of the work, the paper (which of course is constantly accumulating by the motion of the wire-cloth) is directed into the wooden chests *t t;* a pipe pierced with holes extends across the wire-cloth, and the jets of water from these holes detach the paper from the wire-cloth. But should all go well, the wire-cloth, with the wet pulp upon it, is passed between two copper rollers *q q*, covered with woollen cloth; and to prevent the paper from adhering to the cloth, the rollers are kept wet; for which purpose a wooden board covered with felt presses by its edge along the whole length of the top cylinder, the pressure being regulated by weighted levers at the two ends of the board. In this way a sort of trough is formed by the angle of intersection of the board and the cylinder, so that a jet of water introduced on one side flows along the trough and escapes at the other side. *r* is the support to the upper cylinder. At *y* the paper is transferred from the wire-cloth to the blanket, which is supported by the couch rolls *y y*, and kept distended by the roll *z*. The blanket conducts the paper to the press rolls *u u*. These rolls are of iron, cast solid: above the upper roll a steel edge or *doctor* is made to press so as to remove any adhering fibres of the pulp, and to keep a constantly clean surface. Should the paper stick to the cylinder, the doctor prevents it from proceeding further and injuring the blanket. The blanket cannot be used for more than eight days without being removed and washed with soap: with care one blanket may last a month, with three washings. There must always be a supply of blankets, so that a new one may be substituted in case of accident; for if a small hard substance were to become entangled with the blanket, and to pass with it under the rolls, it would make a hole in it and destroy it. The rolls *u u* are adjusted in their bearings by

the screw v, so as to exert a greater or less pressure, and the water which is thus forced out of the paper and blanket is received in the chest x. After passing through the rolls $u\,u$, the paper is conducted by the blanket to within a short distance of the hollow copper roller 1. Here the blanket parts company with the paper, and returns by the rollers $y\,z\,y$, to perform duty again.

The paper proceeds for a short distance without any other support than its own cohesive force, which was in great measure imparted to it by the strong pressure of $u\,u$. The paper proceeds to the upper roll 1, and then obliquely to another pair of rolls $r\,r$, where it meets with a second blanket moving on rolls 2 2, and receives another pressure, any water which escapes being received in a small chest x. The frame, which rises above the rolls $r\,r$, allows a much longer second blanket to be used, the roll 2 supporting it above, and the proper tension being given by the screw w. The paper, after the pressure of $r\,r$, passes over the top roller, and thence to the roll marked 3, and is conducted to the steam cylinder s^1, the mark of the felt being removed by the pressure which it receives between the roller 3 and the cylinder s. A dry blanket, moving on the rollers 4 4, conducts the paper from s^1 to s^2. The number of the steam cylinders may vary from 3 or 4 to 20 and upwards. The steam is conducted into them by pipes from the boiler, as shown in the lower figure. At 5 is a cast-iron cylinder, which presses strongly by means of a weighted lever against the cylinder s^2. At 6 6 are rolls supporting a blanket which conducts the paper first under s^3, which can be made to press with its whole weight on the roll 7, and afterwards over the surface of s^3. At 8 are rolls which serve to adjust the blanket. From the last steam cylinder, the finished paper passes to the drums, or reels, $r'\,r''$, and is wound upon one of them. After the reel has made 130 revolutions, a spring which holds in the ends of the reel is removed. The reel which is attached to the arms, which move on the axis a, is moved quickly round, so as to change places with the other reel: the paper is torn across, the end of the web is attached to the reel now in gear, which is filled while the paper is being cut off the reel last removed.

The paper-machine moves at the rate of from 25 to 40 feet per minute, so that scarcely 2 minutes are occupied in converting liquid pulp into finished paper, a result which, by the old process, occupies about 7 or 8 days. If the machine produce 10 lineal yards of paper per minute, or 600 per hour, this is equal to a mile of paper in 3 hours, or 4 miles per day of 12 hours. The paper is about 54 inches wide, and supposing 300 machines to be at work in Great Britain, working on an average 12 hours a-day, the aggregate length of web would be equal to 1,200 miles, and the area 3,000,000 square yards.

In 1830 Mr. John Wilks obtained a patent for a channeled and perforated roller, called a *dandy*, to remove part of the water from the pulp, to facilitate couching, to enable paper to be made with increased rapidity, and to close its upper surface.

In 1830 Mr. Thomas Barratt obtained a patent for inserting the water mark and maker's name to continuous paper, so as to resemble in every respect paper made by hand.

With respect to the sizing of machine-made paper, it is stated in the Jury Report that sizing in the vat offers many advantages, but as a gelatine cannot be employed without injury to the felt during the process of manufacturing paper, substitutes for gelatine were desirable; and in 1827 M. Canson made size of which wax was the base, and M. Delcambre made another, the base of which was rosin; neither seems to have answered the purpose, for Mr. Obry's plan of using alum and rosin previously dissolved in soda, and combining it with potato starch, which he adopted in 1827, is the method now generally followed in France for writing and printing papers. In England, for printing papers, the rosin size is also the one in use; the addition of potato starch has been attempted, but not very successfully, probably from the quantity of cotton rags used, which seem not readily to take the size made with starch. For writing papers, gelatine is still preferred in this country, and sizing is an after process. At Mr. Joynson's mill, St. Mary Cray, Kent, fine writing paper is now made, sized with gelatine, dried and cut into sheets at the rate of 60 feet a minute in length, and 70 inches in width. Two machines produce 25 tons per week.

The patented improvements relating to the paper-making machine are so numerous that we cannot even give a list of them. We may, however, notice one or two of the most recent. Messrs. Amos and Clark, in 1849, obtained a patent for an improved knotter or pulp-strainer, of which Fig. 1577 is a front elevation; Fig. 1578 is a transverse section on the line A B of Fig. 1577; and Fig. 1579 is a transverse section on the line C D of the same figure,—the sieve-plate being removed. The sieve-plate or knotter, with its frame, may be made in the usual manner. The improvement consists in the mode of getting the pulp through the plates. a is the outer frame or box, resting on

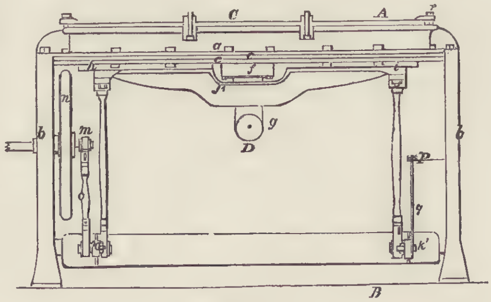


Fig. 1577.

the end frames $b\,b$. c is a belt of vulcanized india-rubber, passing all round the outer frame or box, a, and projecting some little distance within its frame; the belt c rests upon a sheet d of gutta percha, leather, or of vulcanized india-rubber,—the latter having plies of canvas worked within it. The belt c, and the sheet of gutta-percha d, are held fast to

the outer frame or box a, and a water-tight junction is made by the bar e,—bolts being passed through the whole of them, to keep them together. A piece of wood f is fastened beneath the box, having a pipe g passing through it, for the purpose of carrying off the strained pulp to the vat. Two wooden boards or clappers h and i, are fastened to

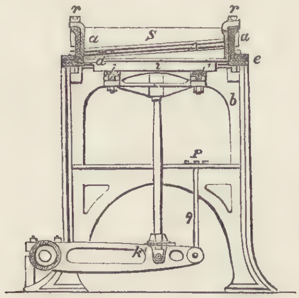


Fig. 1578.

and beneath the flexible sheet d; and the 2 clappers are united together by means of 2 bars j and j^1, which are bolted to them. Connecting-rods attach the clapper-bars j and j^1 to the levers k, k^1; and an alternate rising and falling motion is given to them from the shaft l, through a crank m, on the face of the fly-wheel n; which crank is coupled by the connecting-rod o to the lever k. The radius to the crank m can be varied at pleasure. P is a flat horizontal spring, bolted to the framing b, and intended to balance the weight of the levers k, k^1. From the end of this spring a rigid rod q is pendent, for the purpose of connecting the spring p with the lever k^1. The sieve-plate or knotter A, with its frame S, is placed in the outer frame or box a, and fastened down by the bolts r, r, upon the elastic belt c,—and thus a water and air-tight joint is formed.

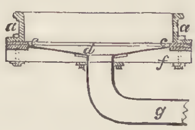


Fig. 1579.

The pulp to be strained is admitted on the upper side of the sieve-plates as usual; and a partial vacuum and plenum is alternately produced beneath the sieve-plates, by the rising and falling of the clapper-boards h, i. The pipe g is carried into the bottom of the vat, which is usually placed before the "wire" of the paper-machine; and a cock, of common construction, is usually placed in this pipe, between the sifter and the vat, for the purpose of regulating the degree of vacuum required beneath the sieves.

In the use of smalt, ultramarine, &c., for writing and other papers, the two sides of the paper become unequally tinged: the under side being of a darker colour than the upper surface, in consequence of the colouring matter sinking to the lower side by the natural subsidence of the water, or from the extraction of the water by the suction-box. Messrs. Amos & Clark propose to remedy this by employing, instead of the common upper couch-roll for working against the upper surface of the paper, a hollow roll, perforated on its surface with a suction-box within it, acted on by an air-pump.

It will be seen in the foregoing descriptions, that great use is made of the air-pump in the manufacture of paper by machinery. We believe that Mr. Dickinson was the first to make this application. In 1809, that gentleman invented a machine for making endless paper. It consists of a polished, hollow, brass cylinder, perforated with holes, and covered with wire-cloth, which revolves over, and just in contact with the prepared pulp. The axis of this cylinder is placed in communication with a pair of air-pumps, and by their action the paper is formed. The film of the pulp adheres to the cylinder during its rotation by atmospheric pressure, whereby it is said to become drier, and of a more uniform thickness than upon the horizontal hand-moulds, or travelling wire-cloth of Fourdrinier. By the rarefaction of the air within the cylinder, the water is sucked in through the cage, leaving the textile filaments so completely interwoven, as if fitted among each other, that they will not separate without breaking, and when dry, form a sheet of paper of a strength and quality depending on the nature and quality of the pulp. The paper thus formed on the hollow cylinder, is wound off continually upon a second solid one covered with felt, upon which it is condensed by the pressure of a third revolving cylinder, and is thence delivered to the drying rollers.

Mr. Dickinson has also applied to the manufacture of paper the principle of veneering in cabinet work. Two webs of paper are made, each by a separate process, and by laying them together while in an early stage, they are rendered inseparable by the pressure to which they are subjected. This paper is used in copper-plate printing, and by adopting a peculiar method of preparing the pulp, and selecting a finer rag for the web, which forms the face of the paper, it is better calculated for taking a fine impression. In what is called *protective paper*, silk threads are introduced into the body of the sheet. By varying the colour of the threads, and their distances apart, various distinctions may be produced. A paper of this kind is used for post-office envelopes and Exchequer bills, as a safeguard against forgery.

The principle introduced by Mr. Dickinson of rarefying the air below the surface of the web, was applied in 1826 by M. Canson to the Fourdrinier machines, as already noticed, see Fig. 1576. In 1836 Mr. Brown, of Esk Mills, near Edinburgh, adopted a similar contrivance. His plan was, to place a rectangular box transversely beneath the horizontal wire-cloth without the interposition of any perforated covering. In 1839 Mr. T. B. Crompton succeeded in producing a uniform rarefaction under the wire-cloth by means of a fan.

Section IV.—Sizes of Papers—Paper-cutting Machines.

Paper is sent into the market in various forms and sizes, according to the use for which it is intended. The following table contains the *names, dimensions,* and *weight per ream* of Writing *and* Drawing Papers :—

	Inches.		Inches.	lbs.
Antiquarian	$52\frac{1}{2}$	by	$30\frac{1}{4}$	236
Double Elephant	$39\frac{1}{2}$	,,	$26\frac{1}{2}$	140
Atlas	33	,,	26	100

	Inches.		Inches.	lbs.
Columbier	34½	by	23	100
Elephant	28	,,	23	72
Imperial	29½	,,	21½	72
Super royal	27¼	,,	19¼	52
Royal	23½	,,	19	44
Medium	22¼	,,	17¼	34
Demy	19½	,,	15¼	24
Extra large thick post	22¼	,,	17¼	25
Extra large thin post	22¼	,,	17¼	18
Extra large bank post	22¼	,,	17¼	13
Large thick post	21	,,	16½	22
Large middle post	21	,,	16½	19
Large thin post	21	,,	16½	16
Large bank post	21	,,	16½	11
Extra thick post	19	,,	15¼	25
Thick post	19	,,	15¼	20
Middle post	19	,,	15¼	17
Thin post	19	,,	15¼	14
Bank post	19	,,	15¼	7
Copy	20	,,	16	17
Sheet-and-half foolscap	25½	,,	13¼	22
Sheet-and-third foolscap	22	,,	13¼	20
Extra thick foolscap	16½	,,	13¼	18
Foolscap	16½	,,	13¼	15
Pott	15½	,,	12½	10

Drawing papers are not made smaller than demy, and are made up into reams flat: writing papers are not made larger than double elephant, and seldom larger than imperial, and are most commonly folded. Laid papers are distinguished by certain water-marks; thus *post* has a bugle-horn; *copy*, a fleur-de-lis; *foolscap*, a lion rampant or Britannia; and *pott* paper has the English arms. These marks enable any one to determine the original dimensions of the paper, however much it may have been reduced in size. There is no water-mark in wove papers. Post papers are not usually sold in the folio; but are cut in half, folded, and ploughed round the edges, forming *quarto-post*, or common letter paper. When this is cut and again folded, it forms *octavo-post* or *note-paper;* another folding forms 16*mo.* or *small note;* and so on up to 64*mo. post*, or lilliputian note-paper. After ploughing, the edges may be left plain or be gilt or blacked. Papers folded the broadest way are named *broad folio*, and the narrow way, *long folio.* There is also *long* or *broad quarto, octavo*, &c.

Printing papers include plate papers, or those used in copper-plate printing. The latter are of the same size, weight, and quality as the drawing papers, but differ from them in being soft and absorbent, the sizing being omitted in the manufacture. Plate papers are not made smaller than medium, which is the size required for the plates of a demy book. When the plates are to be coloured, drawing paper is used, and is termed *hard-plate,* to distinguish it from the former, or *soft-plate.* If plates printed on soft paper require to be coloured, the paper must be sized with a clear solution of isinglass. For taking proofs of engravings, a paper of Chinese manufacture, known as *India paper,* is used. It is very soft and flexible in texture, which enables it readily to take every line of the engraving; it takes the ink well, and dries more rapidly than any other paper. It is imported in sheets 52 inches long and 26 inches wide: the weight varies. The other papers in this class are given in the following table; but the weights and sizes vary with the manufacturer:—

	Inches.		Inches.	lbs.		lbs.
Large news	32	by	22	32	to	37
Small news	28	,,	21	23	,,	25
Royal	25	,,	20	26	,,	28
Medium	23½	,,	18¾	24	,,	26
Demy	22½	,,	18	15	,,	21
Short demy for music	20½	,,	14	25	,,	28
Copy	20¼	,,	16¼	13	,,	16
Crown	20	,,	15	7	,,	12
Foolscap	16½	,,	13¼	9	,,	14
Pott	15½	,,	12¼	9	,,	10½

The last three are always made of double size. Printing papers are usually of a yellow wove texture, and not so well sized as the writing papers.

Wrapping or *packing* papers contain a large variety of sorts and sizes, such as *cartridge-papers, blue papers, hard* or *white-brown papers*, and *brown papers.* Then there is *blotting paper*, made of three sizes—medium, post, and foolscap; *filtering paper*, of the size of double-crown, is thick, and woolly in texture. *Tissue paper* is made of the size of crown, double and single, and demy. *Copying post* is a kind of tissue paper, for copying letters written with copying ink [see Copying machine]. *Littress* is a kind of smooth cartridge paper, used only in the manufacture of cards. A thick purple paper, used by grocers, forms a distinct class, under the title of *sugar-blues.* There is also a class known as *Manchester papers,* made large and coarse for packing; there is also *sheathing paper*, for the use of ship builders, and *tip paper*, for hatters. There are also *coloured papers* of two distinct kinds; one made by colouring the pulp in the vat, and the other kind made from white paper. *Marble papers* have been described under Marbling.

Many of the papers above enumerated are made by hand, of the exact size indicated; but if made by the machine, the roll of paper has to be cut to the required dimensions. In order to do this with precision and expedition, various cutting machines have been contrived; a few of which we now proceed to describe.[1]

One of the simplest of these machines is that by Mr. John Dickinson, an elevation of which is shown in Fig. 1580. The roll of paper, *r*, to be cut, is sup-

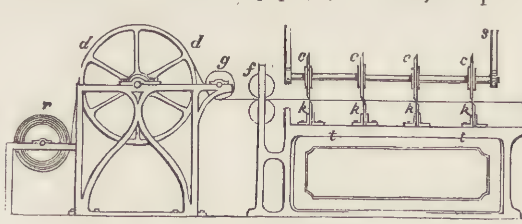


Fig. 1580.

ported by its axis upon an iron frame; and from this roll the paper in its breadth is passed over a conducting drum, *d d*, turning on its axis in a frame; and after passing over a small guide roller *g*, it is passed through a couple of drawing or feeding rollers *f*, which conduct it over the table *t*, where it is cut. Attached to this table is a number of chisel-edged

(1) Other forms of paper-cutting machines are described in Ure's Dictionary of Arts and Manufactures, and also in Hebert's Mechanic's Cyclopædia.

knives $k\,k$, placed at such distances apart as the dimensions of the sheets of paper require. A set of circular cutters $c\,c$, mounted in a swinging frame s, are arranged so as to meet the edges of $k\,k$, and form pairs of shears therewith. The length of paper being dragged forward by workmen over the table t, up to the stop p, the cutters swing forwards, and the paper is cut into four separate sheets. The frame s is hung upon an elevated axle, so that in swinging the cutters may move in a nearly horizontal line: this frame is made to swing backwards and forwards by an eccentric, or crank, fixed upon a horizontal shaft, extending over the drum d, considerably above it, and made to revolve by any convenient power. The work-people draw the paper forwards up to the stop p, in the intervals between the swinging of the frame.

The late Professor Cowper obtained a patent in 1828 for a paper-cutting machine, the details of which will be understood by referring to Fig. 1581. The paper to be cut is first conducted by hand from the reel R, up the inclined plane p; it is then seized by endless tapes extended upon rollers. These tapes convey the paper to the roller c, which bears against the roller c', by means of weighted levers acting on the plummer blocks which support its axle. The second roller c', is furnished with several grooves for receiving the edges of the circular cutters k, which

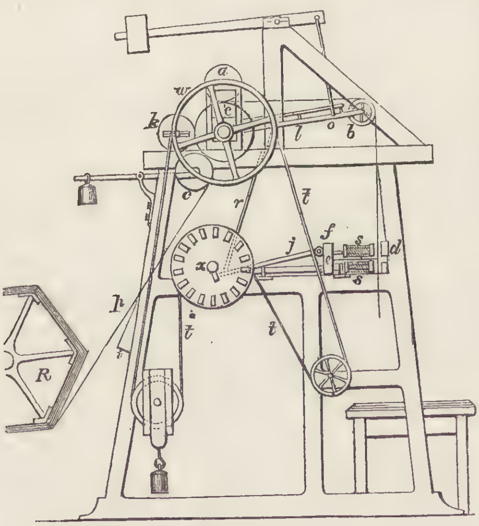


Fig. 1581.

divide the paper lengthwise. A narrow rib of leather is fixed round the edges of one or both the rollers $c\,c'$, to prevent their actual contact, and to allow the paper to pass between them without wrinkling. The paper is then passed, by means of the tapes, from the first roller c, over the second roller c', and then under a pressing roller a, during which progress the paper is divided longitudinally by the circular cutters k, fixed at such distances apart as the width of the sheet of paper may require. The strips of paper thus formed are conducted from under the pressing roller a, by means of tapes to the roller b, when the strips descend to the knife which cuts them transversely. This knife, shown by the black line e, is horizontally placed in the frame at f, and is moved to and fro by a jointed rod j, connected with a crank on the axle of the pulley x. Opposite the knife, and extending across the frame, is a flat board d, furnished with a groove for receiving the edge of the knife. As the paper descends from the roller b, and passes against the face of this board, and as the carriage with the knife advances, two small blocks mounted upon rods with springs $s\,s$, press up against the paper, and hold it firmly to the board d, while the edge of the knife passes through the paper into the groove. The edge of the knife is made on this principle:—The point of a penknife is easily pushed through a sheet of paper, while a straight edge does not pass through without considerable pressure. The knife was therefore made with a series of points, which separated at each cut a row of sheets, which as the blocks receded fell down, and were collected on the heap below.

The power for moving this machine is applied to the axle on which the pulley x is fixed; a band $t\,t$ passing from this pulley over tension wheels drives the wheel w, fixed to the axle of the knife roller c'; by the motion of this roller, the web of paper is moved forward, but the other rollers are driven by friction of contact. The rotation of the crank on the axle of x, by means of the crank rod j, moves the carriage f with the knife to and fro at certain intervals; and when the spring blocks $s\,s$ press against the grooved board d, they slide their guide rods into them, while the knife advances to divide the sheets. By varying the diameter of the pulley x,[1] the rate of rotation of the three conducting rollers $c\,c'\,a$ can be varied so as to cause a greater or less length of paper to descend between every two motions of the knife-carriage, and thus the length of the sheet may be regulated at pleasure.

While the paper is momentarily held by the blocks $s\,s$ in order to be cut, the descent of the paper must be for that short space of time suspended. It does not, however, require that the longitudinal division of the paper should be interrupted; hence the fourth roller b, which hangs in a lever l, is made to rise just at that point, so as to take up the amount of paper delivered, and to descend when the springs at $s\,s$ release the paper. This is brought about by means of the rod r, attached to the crank on the shaft of the roller x, and to the under part of the lever l; this lever hangs loosely on the axle of the knife-roller c' as its fulcrum, and vibrates with the under roller.

In consequence of the construction of the horizontal knife, two of the edges of the paper are left rather rough: this is of no consequence when the edges of the paper have to be ploughed afterwards. It is, however, an objection; and as other machines were introduced, Cowper's ingenious arrangement ceased to be used, except as a model for other men to improve on.

(1) The groove of this pulley is made of wedge-formed blocks passed through its sides, and meeting each other in opposite directions, so that on drawing out the wedges a little, the diameter of the pulley is diminished, and by pushing them in it is increased. The tension-wheel below keeps the band always tight.

Paper-cutting machines now usually form part and parcel of the paper-making machines, so that instead of winding the paper upon a reel as it leaves the steam drying cylinders, and removing this reel as it becomes filled to a separate cutting machine, the reel is dispensed with altogether, and the paper as it leaves the last of the steam cylinders, proceeds at once to the cutting machine. This economical arrangement was, we believe, first made in Mr. Towgood's machine, patented 15th March, 1832. In this machine, the longitudinal section of the paper, as it comes from the drying apparatus, is performed by circular knives as before. In order to cut it into lengths, two conical drums are arranged, one in connexion with the drying apparatus of the paper-making machine, and the other with the cutting machine. The bases of the cones are set in opposite directions, and a strap or other connector is passed over each. From the shape of these drums, the strap may be easily regulated by hand. The roller on which the paper is received from the drying apparatus is connected by a crank with a measuring wheel, set with teeth, and regulated by the action of the crank, so many teeth to such a measure. The paper being already cut longitudinally, is, if necessary, brought out on its feeding roller to another connected with the action of the measuring wheel, and it is there pressed down into a loop, and brought in contact with the transverse cutter, so placed as to pass rapidly and regularly across its breadth, dividing it into the length prescribed by the measuring, when the paper falls into a receiver set on purpose, and is removed in the proper lengths to a heap. In the meanwhile the feeding roller retains its hold, and by a repetition of the process, the next length is brought to the knife in the same manner. The action is commenced by a winch turned by hand or otherwise.[1]

The improvements which have of late years been effected in paper-making machines, admit of their being worked at a much greater velocity than heretofore, and hence great inconvenience has been experienced with the paper-cutting machines in general use, as they cut the sheets of paper into irregular lengths, when working at a speed necessary to keep up with the paper-making machine. To overcome this difficulty, Messrs. Amos & Clark, in November 1849, patented a machine, which is next to be described.

Fig. 1582 shows a side elevation of this machine; Fig. 1583 is an elevation of the opposite side thereof; Fig. 1584 is an end view, taken at the back part of the machine, where the paper is delivered; and Figs. 1585, 1586 show the gathering-roll, and the action of the parts in connexion therewith. Motion is given to this machine by the shaft A, from any prime mover; and the shaft B is driven by a strap passing round the conical drums C and D, mounted respectively on these shafts. The shaft B carries the crank *a*, the eccentric *b* and *b′*, and the rigger or band-wheel E; which latter is for the purpose of driving the fly-wheel E*, and thereby steadying the motion of the machine. This rigger E has a plate, with staple-headed projections cast on its outer side; and through these projections the crank-arm Z passes, and is retained in any required position by the set-screws *d d*. A means is thus presented of altering the radius of the crank to admit of sheets of paper being cut to any required length. The rotary motion of the shaft B gives a reciprocating motion to the gathering-drum F, through the connecting-rod *e*, which is coupled to the crank-pin of the crank-arm Z at one end, and to the lever *f* at the other; which lever is keyed upon the shaft of the drum F. Above the gathering-drum F the rollers *g* and *g′* work in bearings in the cross-head G. An alternate rising and falling motion is given to these cross-heads and rollers by the excentrics *b* and *b′* on the shaft B, through the connecting-rods *z* and *z′*, the levers *h h*, and the vertical bars *i i*; which bars work through guides fastened upon the side-frames of the machine. A presser H is suspended to the side-frames of the machine, by the right-angled levers J and J′; and an

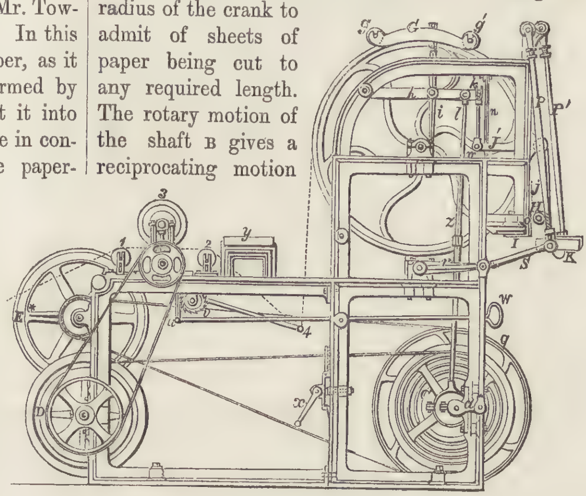


Fig. 1582. SIDE ELEVATION.

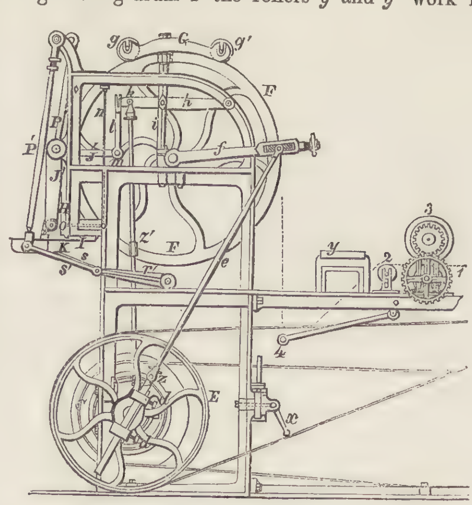


Fig. 1583. SIDE ELEVATION OPPOSITE FIG. 1582.

(1) Repertory of Patent Inventions.

alternating motion is given to it, in order to make it approach to and recede from a stationary presser-

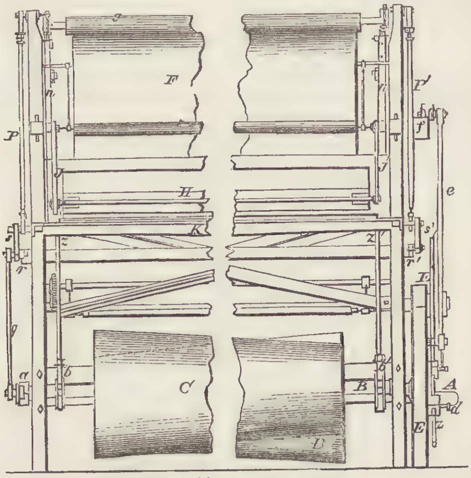


Fig. 1584. END VIEW.

board T, (see Fig. 1585,) and lay hold of the paper as it descends from the drum F, to be divided into sheets by the cutters. When the levers *h* descend, a pin *k* on each side of the machine presses upon the forked ends of the connecting-rods *l*, and thereby causes the end *m* of the right-angled levers J and J′ to descend, and carry the presser H away from the presser-board T. As the levers *h* ascend, the presser H is brought back by the springs *n* (one placed on each side of the machine, and connected to the presser by the connecting-rods *o*). I is the fixed horizontal knife, fastened to the side frames; and the movable knife K is suspended to the side frames by the rods P and P′. Motion is given to this knife by the crank *a*, the connecting-rod *q*, and levers *r r′*, and the connecting-rods *s s′*. The combined motion of these rods and levers admits of the movable knife remaining nearly quiescent for a given time; then, speedily closing on the fixed knife I, it moves over the edge thereof, cutting whatever may be between the knife-edges in the same manner as a pair of shears. The sections Figs. 1585 and 1586 show more clearly the gathering-drum F, the rollers *g* and *g′*, the guide-roller *t*, the movable presser H, and a fixed presser-board T, which forms with H the press for holding the paper.

The paper to be cut passes over the front rollers 1 and 2, between the circular knives 3, and beneath the tension-roll 4, in the usual manner. It then passes over the gathering-drum F, and beneath the rollers *g* and *g′* (which press upon the drum when the paper is being carried forward); and then under the guide-roll *t*, and between the pressers H and T, which, during the progress of the paper, are open to receive it.

The operations peculiar to this machine will be best understood by reference to Figs. 1585 and 1586 :—the arrow, Fig. 1585, shows the direction the paper is travelling. When the crank-arm *z* arrives at the line of centres (as shown at Fig. 1583), the pressers H and T are closed, the rollers *g* and *g′* have begun to rise, and the motion of the gathering-drum F is reversed;—it being made to turn in the direction of the arrow, Fig. 1586. During the time the pressers

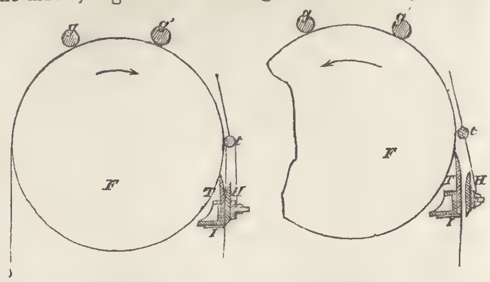


Fig. 1585. *Fig.* 1586.

H and T are closed, the movable knife K is drawn inwards, and the length of paper hanging from the pressers is cut off. As the gathering-drum makes its backward movement in the direction of the arrow, Fig. 1586, it smooths out the paper upon its surface, which is now held between the pressers H and T; and the tension-roll 4 takes up the slack in the paper until the motion of the drum is again reversed. Motion being now communicated to the drum F, in the direction of the arrow, Fig. 1585, and the rollers *g g′* being again brought into their lowest position, a further length of paper will be drawn forward, ready in its turn to be laid hold of by the pressers, and finally cut off into a sheet. When it is required to cut a short sheet, to bring the water-mark more into the centre of the sheet of paper, the action of the tension-roll 4 is stopped by the pall *u* being brought into contact with the ratchet-wheel *v*:—this is effected by the handle *w*. The handle *x* (shown in Figs. 1582 and 1583) is for moving the strap on the conical drums; and the board *y* is merely a stage, to enable the attendant to pass the paper through the machine more readily.

Section V.—Hot-pressing, Glazing, and Finishing—Statistics.

Fine papers are in some cases hot-pressed and glazed. In hot-pressing, a number of stout cast-iron plates are heated in an oven, and then put into a screw press, in alternate layers with highly-glazed pasteboards, between which the paper is placed in open sheets; and the hard polished surfaces of the pasteboards, aided by the heat and pressure, impart that beautiful appearance which belongs to hot-pressed paper. A yet more smooth and elegant surface is produced by the process of glazing. The sheets of paper are placed separately between very smooth clean copper plates. These are then passed through rollers, which impart a pressure of from 20 to 30 tons. After three or four such pressures, the paper is called *rolled*, and sometimes also *hot-pressed;* but if passed more frequently through the rollers, the paper acquires a higher surface, and is then called glazed. See Cardboard.

In glazing papers with copper plates it has been found that, through the curvature of the rolls, the pile of paper between the copper plates is sometimes disturbed, and the edges become frequently blackened in consequence. To obviate this defect, Messrs.

Amos & Clark employ rolling-machines of the construction shown at Fig. 1587. This figure shows, in section, 3 pairs of hollow pressing rollers, but more or fewer pairs may be used, if required. Between these rolls, which are suitably mounted, a wrought-iron plate, for carrying the pile of paper to be glazed, is made to traverse, by means of a reversing motion with which the rolls are provided. *a, b, c, d, e,* and *f,* indicate the 3 pairs of rolls; *g,* is the metal plate; and *h, i,* show the piles of paper, with their layers of copper-plates or glazed boards, as usual. *j, k, l,* are 3 wheels, keyed upon the rolls, and driven by the pinion *m* (from any prime mover);—the wheel *j* is keyed on the roll *a*, the wheel *k* on the roll *e*, and the wheel *l* on the roll *c*. The pinion *m* works into the wheel *k*. On the opposite side of the machine (but not shown in the drawing) other wheels, of similar diameters, are placed on the rolls, *b, d,* and *f;* and a similar pinion to *m*, and keyed on the same shaft, works into the wheel keyed on the roll *f;* by which arrangement the whole of the rolls are driven in the proper direction.

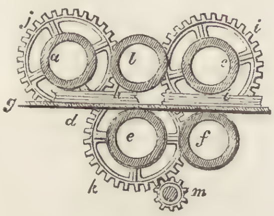


Fig. 1587.

The general introduction of steel pens has increased the demand for smooth papers, and has led to improvements in finishing them. By passing writing papers in long lengths through naked rollers, the latter soon become indented. A better plan is to pass the paper several times through a calender, having an iron roller at the top and bottom and a paper roller in the middle, the iron rollers being slightly heated by steam. It is remarked in the Jury Report, that "there is no difficulty in glazing papers in long lengths, provided care be taken to obtain very true rollers.[1] A thin ductor blade should be fixed in a proper position, to detach the sheets as they pass through, as the electricity which is developed causes them to adhere to the cylinders, particularly where rosin size has been used."

In drying machine-made papers, more attention is now paid to the surface than formerly. Messrs. Amos and Clark remark, that "in heating the drying-cylinders for drying the paper by steam, it is known that this operation is better effected when a varying temperature is given to each cylinder: thus the cylinder which receives the paper first is preferred to be cooler than the following one, the second cylinder cooler than the third, and so on. The character of the paper, when dried under such circumstances, approaches more nearly to the 'loft-dried paper,'—it being tougher in quality, and without the harshness of machine-made papers when dried in the usual way. The usual mode of regulating the steam pressure in the cylinder has been by the common steam-cocks; but, as this is attended with much uncertainty, they have patented a pressure-regulating valve, for regulating at pleasure the pressure in the cylinders. This valve is shown in sectional elevation at Fig. 1588, wherein A is a cylinder, having a piston B, nicely ground and fitted, working within it. C is the piston-rod, passing loosely through the crown of the cylinder, and carrying a weight D. E is the valve-seat, being a hollow cylinder, having four or more ports or openings in its periphery; three of which ports are shown at *a a a*. F is the valve, being a cylindrical ring of metal, which is made to slide on the valve-seat E, by means of the connecting-rods G and G′, which couple it with the piston B by the cross pin *b*. H is a cylinder, or steam-box, having the upper cylinder A bolted to it; and the cylinder, or valve-seat E, passing through it, is secured in its place by the nut *e*. The valve-seat E is attached by the pipe J, to the pipes leading from the steam-boiler: and the pipe I leads from the steam-box H to the drying-cylinder. One of these regulating valves is required for each drying-cylinder. When the weight D is in its lowest position, as in the figure, the sliding-valve F is also at its lowest position, and the ports *a a a* are open;—thus allowing the steam to pass from the boiler into the drying-cylinder in the direction of the arrows. When the pressure in the drying-cylinder, and in the steam-box H, exceeds the resistance offered by the weight D to the piston B, the piston will be raised by the pressure of the steam, and thereby carry up the sliding-valve F, and close the ports *a a a* to the proper degree for the pressure required, which is when that pressure and the resistance from the weight D are in equilibrium. When the piston B rises sufficiently to bring the surfaces *c c′* of the sliding-valve F in contact with the surfaces *d d′* of the valve-seat E, the openings *a a a* will be closed, and no steam can pass from the boiler through the pipe I to the drying-cylinder in connexion therewith. By placing weights of different sizes upon the pressure-regulating valve of each drying-cylinder, any required pressure of steam can be maintained therein."[2]

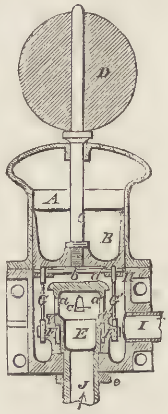


Fig. 1588.

(1) A method of making cast-iron rollers truer than is possible by turning in a lathe, was invented by Mr. Thomas Barratt of St. Mary Cray, and is described in the third volume of Holtzapffel's *Mechanical Manipulation.* It consists in merely grinding the rollers together with water, without the application of emery or any other grinding material. The grinding action appears to be chiefly due to the small particles of cast-iron rubbed off by the friction, and which serve as the abrading powder. The grinding, which lasts several weeks, may be expedited by using the same water repeatedly over again; but towards the conclusion, when high finish is required, clean water is alone used. For a very high finish, oil instead of water is used towards the end of the process.

(2) The patentees state that this regulating valve may be applied to various purposes,—as, where steam of any high or varying pressure is required to be reduced to an uniformly low pressure. The valve will be also useful in reducing the pressure of columns of water,—as when attached to a high-service main,—and obtaining an uniformly low pressure. The pressure of air, gas, and other fluids, may be in like manner regulated by this valve when required.

As an improvement in the manufacture of paper sized by the machines now in use, the patentees propose to conduct the web of paper, after it has been either partially or completely dried, through a trough of cold water, then to pass it through a pair of pressing-rolls, and afterwards to dry it on reels, or over hot cylinders. The paper thus treated will be found to "bear" much better, and admit of erasures being made on the surface of such paper, and written over, without the ink running in the way it does when the paper is sized and dried in the usual manner.

It has been found that when paper is dried, after sizing, by the drying-machines in present use, the paper is very harsh, and, until it stands for some time to get weather (as it is technically termed), great difficulty is experienced in glazing the paper. This inconvenience is proposed to be overcome by passing the paper partially round a hollow cylinder, through which a small stream of cold water is made to run. By this means the heat in the paper is carried off, and the paper is rendered more tractable, and brought to a proper state for undergoing the glazing operation.

It is stated in the Jury Report, that "in England writing papers are sized with gelatine, and are stronger and harder than those of other countries; they are also cleaner, generally better *put up*, and show greater care in the manufacture, than those of France and of other countries. The old cream-laid papers, now so fashionable in England, were re-introduced by Messrs. Hollingworth, of Turkey Mill, Kent, a few years since, and they are still preferred for letter and note-paper. The thinner post writing papers, however, are much better manufactured in France, Belgium, and other parts of the continent, than in England. Those exhibited from Angoulême in France, and Heilbronn in Germany, are the best; those made in Belgium are not sufficiently hard-sized. Notwithstanding the high protective duty of 4½*d.* per pound, a considerable quantity of these thin writing papers is imported into England. The white of the letter-papers of France, Germany, and other foreign countries, is of great purity and beauty: and these papers being sized in the vat with farina, in addition to rosin-soap, instead of gelatine, they are less greasy under the pen, and consequently can be written on more freely than those which are sized with animal size; they do not, however, bear the ink so well. English printing papers generally maintain a superiority over those of foreign countries; and in drawing papers and strong account-book blue-laid papers, England stands unrivalled. Tinted printing and drawing papers, formerly made exclusively in England, are now produced by most foreign paper-makers, who also make the tinted writing post papers, long out of fashion in this country. M. Obry of Prouzel exhibited well-made black papers for wrapping cambrics, lace, &c. Black papers of the same kind were made in Ireland and Manchester more than twenty-five years ago."

The following is an account of the number of paper-mills in England, Scotland, and Ireland, with the number of beating-engines employed; also the amount of duty charged on paper, the quantity imported from various countries, and the amount exported from Great Britain in 1850:—

	England.	Scotland.	Ireland.
Number of paper mills.........	327	51	37
Number of beating engines...	1,374	286	86
	lbs.	lbs.	lbs.
Paper charged with duty	105,712,953	28,600,019	6,719,502
Amount of duty	£693,741	£187,687	£44,096
Paper Imported—			
	sq. yds.	sq. yds.	
Printed, painted, stained, or hangings	342,746	470	—
	lbs.	lbs.	
Other kinds	267,162	53	—
Amount of duty	£5,607	£5	—
Paper Exported—			
	sq. yds.	sq. yds.	
Printed, painted, or stained ..	1,155,022	163,164	—
	lbs.	lbs.	lbs.
Other kinds	6,568,268	1,040,555	9,248
Amount of drawback paid	£43,934	£6,946	£60

It appears from a parliamentary paper, published 9th March, 1852, that on the previous 18th February the number of paper-mills at work in England was 304, in Scotland 48, in Ireland 28; making 380. There were 1,616 beating-engines at work, and 130 silent.

The amount of duty charged in 1850, shows the enormous amount of 62,960 tons weight of paper produced in Great Britain in one year. The annual value of paper manufactured in this country is estimated at two millions sterling.

PAPER-HANGINGS. The fashion of covering the walls of apartments with decorative paper-hangings, or, as the French call them, *papiers peints*, has been derived, like paper-making, from that ingenious people, the Chinese. The art of making paper-hangings has existed among them from time immemorial, and England, it is said, was the first country to imitate the specimens of their skill which had been imported hither.

To this art we are indebted for much of the appearance of comfort and respectability which prevails in the houses of the middle and lower classes of this country. The wealthy might, and often do, adopt other modes of ornamentation, but for the professional and working classes, paper-hangings, varying in price and in style, afford the means of clothing the walls of their dwellings cheerfully and pleasingly, and in a more or less elegant manner according to the means of the owner. Paper-hangings, even of the lowest price and quality, may yet, by their simplicity and good taste, greatly enhance the beauty of a cottage, and increase the sense of comfort in its occupants. For there is no question but that the feeling of comfort is largely influenced by the colour and fitness of the objects around us. Who has not felt relieved on entering a room with a cold northern aspect, to find the walls covered with rose-coloured, or crimson paperings, or with paper in which the warmer tints predominate? and who has not experienced, on the other hand, a sense of coolness, on finding a room with a bright southern aspect, judiciously papered with an admixture of a cold colour, such as a bluish green, (in contradistinction to the bright yellowish green,

which gives a sense of heat rather than of coolness)?

The apparent warmth or coldness of a room is not the only point on which it is influenced by the nature of its paper-hangings: its apparent size and height are increased or diminished by the same means. Papers of a large pattern greatly reduce the apparent size: those of a large and flowing pattern the height; a paper in which perpendicular lines predominate, although the pattern be large, does not so much affect the apparent height. To cover a small room with paper of a large pattern is a great mistake; a still worse mistake is to paper the ceiling, as is sometimes done on the continent.

The best effect is produced by using papers in which the pattern and colours are quiet and harmonious, and do not strike the eye. The walls of a room are like the back-ground of a picture, and should be so treated as to relieve and set off the objects in front of them, and to give repose to the eye. A paper presenting sudden contrasts in colour, and strongly marked lines in the pattern, forms the worst possible back-ground for pictures, and the most unfavourable accompaniment to furniture, draperies, and objects of taste. The spotty effect of such a papering interferes with all the minor objects in the apartment, and gives an unpleasant and bewildering effect. Modern paper-hangings are frequently made to represent columns, friezes, pilasters, &c., dividing the room into compartments. Notwithstanding the beautiful execution of some of these papers, they cannot be recommended as in good taste. The introduction of real objects of the kind would be an absurdity in a situation where their support is not needed; therefore why should we have sham pilastres, &c.? The introduction of flowers and conventional forms for the ornamentation of our walls is not unnatural; consequently their imitation does not involve an absurdity. It was suggested, a few years ago, that paper-hangings might be made instructive, as well as ornamental, by the introduction of poetical and other sentences of a moral and religious kind. In former days it was not uncommon to have the walls adorned with tablets, containing sentences from various authors, for there are drawings still extant of those which ornamented the apartments of Sir Nicholas Bacon. It has therefore been thought desirable that paperings of a similar kind should be prepared, with compartments, representing tablets, in which appropriate mottoes should be printed in the old English or German characters. This custom would be liable to many abuses, arising from the defective tastes of those who had the choosing of the mottoes; but perhaps this is not a sufficient reason why we should discard a practice which might be productive of useful results.

The early method of making paper-hangings was by *stencilling*, as that mode of painting was called, in which a piece of pasteboard, or sheet-metal, with patterns cut out in it, was laid on the paper, and water-colours were applied with a brush to the back of the pasteboard, so that the colours were delivered through the openings, and formed the patterns upon the paper. When the first series of colours had become dry, another might be applied with a second piece of pasteboard, and so on, until considerable variety was attained, but at much cost of time and trouble. These processes were afterwards superseded by those of the calico-printer, which were successfully applied to the manufacture of paper-hangings, the pattern being engraved on wood-blocks made from the pear-tree or sycamore, and the coloured designs printed from them by hand, on papers previously prepared, by laying on them a uniform ground of some earthy colour thickened with size.

The progress of improvement in this manufacture was, however, greatly checked in England by the high protective duty of one shilling per square yard, which existed up to the year 1846, and which almost entirely excluded the works of foreigners. Thus our own manufacturers had little stimulus to improvement, and were unable to profit by the French modes of manufacture, which progressed rapidly. In the above year the duty was reduced to twopence, since which time great progress in the manufacture has been made in this country, both as to style and workmanship.

In printing by hand, as many blocks are required as there are shades and varieties of colour. In the Great Exhibition there were to be found specimens of decorative paper-hangings requiring a large number of blocks to produce the pattern. The labour and skill bestowed on some of these were immense, but the effect was not always proportionally good. In fact, the attempt to bring as many colours as possible into one composition is very much to be deprecated. The result may astonish those who are aware of the number of the processes adopted, but it will be seldom pleasing to persons of good taste.

The blocks of the paper-hanger, like those of the calico and floor-cloth printer, consist of engraved pieces of pear-tree or sycamore, mounted on poplar or pine-wood. Each has 4 pin-points at the corners, which make guide-marks on the paper for placing the succeeding blocks in the same spot. These blocks are pressed on the sieves of colour, and applied in succession with some force to the paper. These sieves or drums are covered with calf's-skin, and float in a tub of water thickened with parings of paper from the bookbinders. The drum is kept uniformly covered with colour by a child, who takes up a small quantity on a brush, and distributes it afresh over the surface after every application of the block. The workman, in pressing down the block charged with colour on the surface of the paper, employs a lever to increase the power of his arm, the child drawing away a portion of the paper at intervals across a wooden trestle, —hence the name of *tireur* (drawer) given to the child. When the piece has received one set of coloured impressions, the workman, assisted by the drawer, hangs it up to dry, on poles near the ceiling, to which hooks are attached. If the paper is of the description called flock-paper, the pattern is first printed in size, then with a preparation of varnish, and before this is dry, the coloured flock prepared from wool is sifted

over the paper, and adheres to the varnished parts. The preparation of the flock is as follows:—When obtained from the woollen cloth manufacturers it consists of particles cut off by the shearing machines, and may be either white or coloured; if white, it has to be scoured and dyed to the proper tint. It is then stove-dried and ground to a fine powder. This is further prepared by sifting to different degrees of fineness in a bolting-machine. It is then placed in a large chest, or *drum*, whose width and capacity are such that the child can draw the printed paper into it by degrees at its full width, and sprinkle the flock thereon. When about 7 feet of papering have been thus drawn in, the child shuts the lid of the drum, and beats with rods on the bottom, which is made of tense calf's skin, and is elevated 2 feet from the floor by means of strong supports. This beating on the drum raises a cloud of flock inside, which, as it subsides, falls uniformly on the paper. The chest is then opened, the paper is inverted, and lightly tapped to detach loose particles. Gradations of colour in the flock are afterwards produced by applying to the surface, when thoroughly dry, lighter or deeper shades in water-colour or in distemper. Gold-leaf is applied to paper-hangings in the same way as to wood, and by means of a preparation washed over it, is made more durable than formerly, and better able to resist damp.

A great change has been made in the manufacture of paper-hangings during the last ten years, by the introduction of machine printing. By means of steam-power, an endless roll of paper, and artificial drying, the system of surface-roller printing in several colours, as described under CALICO-PRINTING, is now successfully applied to paper-hanging. Papers thus produced are not equal to those done by hand, but they can be so cheaply produced, that they command an extensive sale. Machine printing has not yet succeeded with papers in which glazed or satin grounds are required. In the Great Exhibition were specimens of machine-printed paper showing 14 colours: others showing 20 colours, made by 14 rollers. It is stated that each machine is capable of printing from 1,000 to 1,500 pieces per day. It is estimated that in 1851 there were produced in Great Britain, 5,500,000 pieces, of the value of 400,000*l.*

PAPIER MACHE. Articles so named are produced either by pressing the pulp of paper between dies, or by pasting paper in sheets upon models. The articles when dry are varnished, japanned, and ornamented. By the first method, a variety of cheap articles is manufactured in Paris; the materials for the pulp, viz. paper and paste, being supplied by the bill-stickers, whose bills having served the purposes of advertisements by day, are, by night, pulled down and taken to the factory, *mashed* in water, and pressed in moulds. The second method is the superior of the two, and is thus conducted at Birmingham:—Paper of a porous texture, saturated with a solution of flour and glue, is applied to an iron, brass, or copper mould of somewhat smaller size than the object required: repeated layers of this paper are put on with glue, a drying heat of 100° being applied after every new coat. When a sufficient thickness is attained, the shell is removed from the mould, and planed and filed to shape. About 10 layers are used for an ordinary tea-tray; more or less for other articles, according to circumstances. A tar-varnish mixed with lamp-black is next laid on, and the article is stoved. Several coats of varnish are added, with a stoving after each. When sufficiently covered with this preparation, the inequalities are removed with pumice-stone, and the artist applies the ornament in bronze-powder, gold, or colour. Several coats of shell-lac varnish are then put on, and the article is stoved at a heat of 280°. The article is polished with rotten stone and oil, and brought to a brilliant surface by hand-rubbing.

A favourite material for ornamenting papier-maché articles is mother-of-pearl, and the artist cannot certainly be accused of want of liberality in the use of it. In the Great Exhibition the gaudy, over-ornamented papier-maché articles in the English department produced a painful effect, and clearly proved that the art of design in this material is unknown in this country: the impossible landscapes, the mother-of-pearl rivers and moonlights, might have excited a smile, had not the display told of a vast amount of labour and ingenuity thrown away. Some very common articles in japanned ware, from Japan and China, were in excellent taste, showing, as the Jury Report well remarks, that "vulgar forms and bad ornament are not necessarily connected with cheap manufacture."

The largest manufacture of papier maché in England is that of Messrs. Jennens and Bettridge, at Birmingham, whose factory, which is open to the public at stated times during the week, we have had much pleasure in visiting. Among the endless variety of objects exhibited by them in this material were tables, chairs, screens, work-boxes, inkstands, portfolios, and a piano. Many of the articles were ornamented in good taste, but the great fault of over-ornamentation was evident in nearly all cases.

Papier maché used for architectural purposes is prepared by laying sheets of brown paper one over the other, with a coat of glue between every two layers. This mass of paper is pressed into a metal mould of the ornament required: the moulded paper being trimmed to shape, a composition of the pulp of paper mixed with rosin and glue is put into the mould; the paper is again inserted and pressed upon the pulp composition which adheres to it, and produces a sharp well-defined ornament.

Carton-pierre ornaments are also composed of the pulp of paper mixed with whiting and glue, pressed into plaster piece-moulds backed with paper, and when sufficiently set, hardened by drying in a hot room. Carton-pierre is stronger and lighter than plaster-of-Paris.

PARACHUTE. See AEROSTATION.

PARAFFINE. See Introductory Essay, pp. lxxxiii. and lxxxv.

PARAPET (Italian *parapetto*, from the Greek *πάρα*, against, and the Italian *petto*, the breast), a low or breast-high wall or fence, used as a protection on bridges, terraces, platform roofs, &c.

PARCHMENT, the skin of an animal prepared for writing on. The name is from the Latin *Pergamena*, from *Pergamus*, the reputed place of its invention. Eumenes II. king of that place (who reigned B. C. 197—159), has the honour of the invention, he being stimulated thereto by the prohibition of the export of papyrus from Egypt. Some authorities consider Eumenes to have been only an improver of the art of preparing skins for writing on, which Herodotus says were commonly used for that purpose in his time; and it is even asserted that the word *pergamena* was not used until several centuries after the death of Eumenes. According to Mabillon, the first writer who uses the term is Tatto, a monk of the fourth century; before his time, the word *membrana* was employed, as in the Greek Testament, 2 Tim. iv. 13.

In a small work on *Arts and Trades*, published at Frankfort in 1568, there is a cut representing the parchment-maker at work with tools and apparatus similar to those now in use. The skins of most animals are adapted to the manufacture of parchment, but as the better kinds of skins are in great demand for making leather, sheep-skins are commonly used. The finer kind of parchment, called *vellum*, is made from the skins of calves, kids, and dead-born lambs: the stout parchment used for drum-heads is made from the skins of asses, calves, or wolves, the last-named being preferred; the parchment of battledores is from asses' skin, and for sieves the skin of the he-goat is preferred. The skins are all prepared in a similar manner. When the hair or wool is got off by some of the processes described under LEATHER, the skin is put into a lime-pit, and when the fat has completely combined with the lime, the skin is stretched upon a stout wooden frame or *herse*, Fig. 1589, consisting of 4 bars perforated with holes, each of which is occupied by a peg. By means of these pegs the skin is stretched in the frame, for which purpose a number of pieces of twine are tied firmly to the edges of the skin, and to prevent the skin from slipping when strained tightly, each string is tied round a small wad or ball, formed by making a small fold at the side of the skin, and rolling up a shred of skin in this fold. In some cases skewers are stuck into the edges of the skin, and the string is tied firmly to them. In either case, the other end of the string is passed through a hole in the side of the peg, and in turning this the string is wound round it, and thus the skin is gradually and equally strained, great care being taken to prevent the formation of wrinkles. The herse is then set up against a wall, and the surface scraped with a double-edged knife, Fig. 1590, (called from its shape a *half-moon* knife,) attached to a double handle. The skinner uses this knife with both hands, and pressing the edge againt the skin, first on the flesh and then on the grain side, thus gets rid of fleshy substances, dirt, slime, &c.

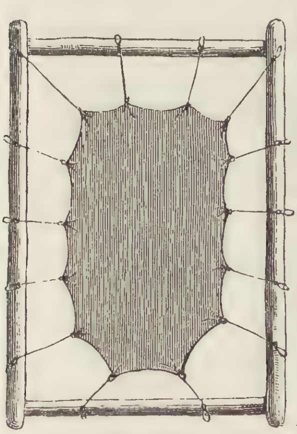


Fig. 1589.

Fig. 1590.

In the next process, called *grinding*, the frame is placed on trestles; the skin is sprinkled on the flesh side with finely-powdered chalk or slaked lime, and then rubbed in all directions with a flat surface of pumice-stone. The grain side is ground with pumice only. The knife is again passed over the skin, the scouring with chalk and pumice repeated. This scraping with the knife is called *draining*, and serves to whiten the skin. Fine chalk is then rubbed over both sides of the skin with a piece of lamb-skin with the wool on; this serves to whiten the skin and to give it a white down or nap. The skin is then removed to a covered shed to dry, and in warm weather a wet cloth is occasionally applied to it, and the pegs tightened. When quite dry it is well rubbed with the woolly side of a lamb-skin to get rid of the chalk. Should any greasy matter now be detected in the skin, it is removed from the herse and steeped in the lime-pit for some days; otherwise it is cut all round to get rid of the wads, and transferred to a man called the *parchment maker*, who stretches it tail downwards upon a machine, called the *sumner*, consisting of a calf-skin mounted on a frame. He then passes a sharp circular knife over the grain surface of the skin in an oblique direction, and pares off about half the thickness of the skin, leaving a perfectly smooth surface, an operation requiring a flexible wrist and considerable skill. The skin is scraped on the grain side only: should any roughness appear, it is removed by rubbing with pumice-stone, for which purpose it is placed upon a form or bench covered with parchment and stuffed with flock. After this the parchment is fit for writing on. If any small holes appear in the skin they are stopped by cutting the edges thin, and laying on small pieces of parchment with gum water.

The green colour given to the parchment used for bookbinding is given by boiling in 500 parts distilled water, 8 parts cream of tartar, and 30 of crystallized verdigris; adding 4 parts of nitric acid when the solution is cold. The parchment having been moistened with a brush, the colour is spead evenly over the surface. Polish is given by white of egg, or mucilage of gum arabic.

PARING-KNIFE, a lever knife about 3 feet long, one end terminating in a hook, and the other in a transverse handle. The hook plays in an eye-bolt attached to the bench or block, and below the cutting edge, which is towards the hooked end, is a detached cutting board for supporting the wood to be shaped, and for receiving the edge of the knife. The paring-knife is used by the turner to prepare woods for the

lathe; also by the makers of shoe-lasts, clogs, pattens and toys. The edge of the knife is sometimes curved like a gouge.

Toy makers are accustomed to use a paring-knife with an edge 12 or 14 inches long, and working in a guide. The pieces of birch, alder, &c., used for parts of toys are softened by boiling in water for about an hour, and while hot are worked with great ease and precision, slices being pared off in the direction of the

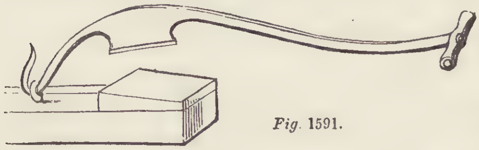


Fig. 1591.

grain measuring 4 by 6 inches: these are wedged tight in rows, and thus dry quite flat, so as to require no further smoothing. Small cart wheels 1 or 2 inches in diameter and $\frac{1}{4}$ to $\frac{3}{8}$ inch thick are thus cut across the grain out of cylinders previously turned and bored, the hot wood being so flexible that it yields to the knife without breaking transversely.

PARQUETRY. See MARQUETRY.

PARTING. See ASSAYING—SILVER.

PARTITIONS. See FLOORS.

PASTES, OR FICTITIOUS GEMS. See GLASS, *Sec.* IV.

PASTILLES, small cones made of gum benzoin, powder of cinnamon and other aromatics, and used for burning as incense, or for diffusing a pleasant odour through an apartment. The term *pastille* is also applied by the French to certain aromatic sugared confections: they are also named *tablettes.*

PATTERNS. See CASTING AND FOUNDING—also CALICO PRINTING—WEAVING.

PAVEMENT. See ROAD—TILES.

PAVING. See ROAD.

PEARL. A shelly secretion of a spherical shape formed in a species of oyster, or pearl mussel, and said to be produced by a malady in the animal, which requires nearly seven years for its full development, after which the oyster dies. Small pearls which have been immersed in acetous acids, and thus reduced to their membranous constituents, have the appearance of being formed of concentric coats of membrane, and carbonate of lime, thus resembling in composition the mother-of-pearl with which oyster-shells are lined. The precise origin of pearls is unknown, but it appears probable that some minute substance, such as a grain of sand, may have found its way into the shell and produced irritation, and that the animal, unable to expel it, renders it less injurious by covering it with calcareous matter. It is sometimes affirmed, that to produce pearls, the oyster must have received some external injury; and this is corroborated by the fact that nearly all the shells in which pearls are found are outwardly contorted, and that a smooth regular shell is a pretty sure sign of the absence of the pearl. It was therefore suggested to the Swedish government by the celebrated Linnæus, to pierce small holes in the shell of the freshly-caught pearl oyster, and then restore it to its original bed. The experiment was tried, but without success. A somewhat similar plan is said to be adopted by the Chinese, and with favourable results. These ingenious people thread upon fine silk small beads of mother-of-pearl, and fasten them within the shells of pearl oysters, when they rise to the surface of the water at the beginning of summer. The animals are then restored to their bed, where they soon cover the beads with calcareous matter, and thus convert them into pearls.

In whatever way produced, pearls of considerable size, on account of their beauty and rarity, have been valued at enormous prices in past ages, and are still among the choicest objects of the jeweller's art. Their delicate and silvery lustre has been as widely celebrated as the brilliancy of the diamond. The Hindoos poetically describe them as drops of dew falling into the shells when the fish rise to the surface of the sea in the month of May, and becoming by some unexplained action of the sun's rays transformed into pearls.

Pearl fisheries exist in Ceylon, on the Coromandel coast, and in the Persian Gulf, the last-named being the most productive. Fisheries of less importance also exist in Algiers, and in the Zooloo Islands. Two thousand years ago the Romans found pearls in Britain, and within modern times the rivers of Scotland have afforded considerable quantities, though not of the best quality. Several rivers of Saxony, Silesia, Bavaria, and Bohemia afford pearls, and they are also found in two or three Russian provinces. There are also pearl fisheries in the western hemisphere. The coast of Columbia and the Bay of Panama have furnished considerable quantities, but they are not considered equal to the pearls of the East in shape or colour. Detailed accounts of the pearl fishery of Ceylon have been given by the Count de Noé and others who have had ample means of watching the operations of the pearl-divers during a residence in that island. It appears that the pearl oysters occur in banks at greater or less depth in the sea on the western side of the island of Ceylon, the average depth, however, being about 12 fathoms, and the distance from the shore about 15 miles. The right to fish on these banks is sold by the government every season, and a single auction sale is generally made to one individual, who afterwards disposes of shares in the fishery to other parties. The biddings at the auction are regulated by the produce of some thousands of oysters taken from the beds at hazard. If the average quality of pearls contained in them be good, the competition is strong in proportion.

The pearl fishery commences in April and lasts till towards the end of May. It attracts a concourse of visitors not only from the interior of the island, but from various parts of India, whose diversities of language, dress, and manners produce a striking effect. The sea-shore, at other times solitary, is on the eve of the fishery suddenly covered with innumerable huts, composed of a few poles stuck in the ground, interwoven with bamboo and covered with the leaves of the cocoa-nut palm: these temporary dwellings often shelter as many as 150,000 persons. The signal for commencing the fishery is given at

day-break by the firing of cannon, and at that moment the several boats cast anchor in the fishing ground, for at midnight they had left the shore in an extensive fleet, so as to be on the spot at the desired moment. Each boat has its own proper bounds, beyond which it is not lawful to work, and government vessels are on the spot to see that no infringement of contract takes place. The boats each carry a captain, a pilot, and 20 men, of whom 10 are experienced divers. 5 divers descend at once, the other 5 taking the plunge when the first ascend. Thus a little time is allowed for regaining strength. In order to descend as rapidly as possible through the water, the diver places his feet on a large stone made fast to one end of a rope, the other end being secured to the boat. He also takes another rope, to the end of which is attached a net, or basket, to contain the oysters. The upper extremity of this second rope is held by two men in the boat. The diver is also provided with a strong knife for detaching the oysters, and as a means of defence against sharks, which are very numerous in those seas, but which do not often attack the divers, being perhaps scared by the noise of the assemblage, and the continual plunging of so great a number of persons. The diver no sooner reaches the ground than he gathers oysters with all possible speed into his basket, and then letting go the rope to which the stone is attached, he pulls that which is held by the sailors, and rapidly ascends to the surface. Some divers make very dexterous use of their feet, holding the net with one foot, clasping the stone with the other, and thus leaving one hand free to close the nostrils, while the other hand holds the rope in descending.

The time during which the divers can remain submerged is variously stated, and no doubt it differs greatly according to the constitution of the individual. Some observers declare that in their experience it never exceeded 50 seconds; but Captain Percival, in his work on Ceylon, gives 2 minutes as the usual time of remaining under water.[1] Serious effects are produced by this employment, and the divers may frequently be seen with blood issuing from their mouth and nostrils. Yet this does not hinder them from going down in their turn. They will make from 40 to 50 plunges in one day, and bring up on each occasion about 100 oysters. Their day closes before noon, for as soon as the sea-breeze sets in, the signal is given for the return of the boats to the shore. Their owners, and a large assemblage of persons of all classes, are eagerly looking out for the arrival of the flotilla, and are soon busily employed in examining and stowing away the cargoes.

Each owner has a shallow pit fenced round and secured for his own use, in which his store of oysters is deposited, and left open to the air. This pit, or *couttó*, as it is called, is in the midst of a group of huts belonging to the same owner, so that it is under guard of his party. Here the oysters are allowed to putrefy under a burning sun, and a stench arises from them which would seem enough to depopulate the shore of its thousands of inhabitants. Yet such is not the case. The health of the people does not appear to be materially affected, and the oysters are allowed to remain till dry, when they can be easily opened and the pearls extracted. To open them when fresh would require much greater force, and would be likely to injure the pearls. When the putrefaction is sufficiently advanced, the oysters are taken from the *couttó*, and placed in troughs made of the trunks of trees. Sea-water is thrown over them: they are easily opened, and render their pearls to the washing and shaking of a number of men who stand all on one side of the trough, while inspectors at each end closely watch their proceedings, and other inspectors examine the shells which are thrown away, lest they should contain some of the precious substance. The workmen engaged in washing pearls dare not lift their hands to their mouths under penalty of a flogging, yet a man will sometimes contrive to swallow a pearl of high price. After all the pearls are washed out, the largest are carefully picked out from the sand at the bottom of the troughs and washed repeatedly in clean water: the next in size are spread out on white napkins to dry in the sun. The remainder are left to the care of women, who pick them up and dry them. Pearls are assorted by means of three sieves placed one above another, the meshes in which are smaller as the pearls descend. Thus the pearls which will not pass through the uppermost sieve are of the first class, and so on with the others. Another assortment is made as to colour, regularity of form, &c., and here the tastes of different nations have to be consulted. The Europeans prefer pure white pearls, the Indians yellow pearls, and the natives of Ceylon those which are tinged with rose-colour.

Besides the number of persons who arrive in Ceylon in the fishing season for the sake of speculating in pearls, there are also numerous Indian artisans who are very expert in piercing and drilling pearls, and who practise their trade on the spot on economical terms. Captain Percival thus describes their operations:—"A machine made of wood, and of a shape resembling an obtuse inverted cone, about 6 inches in length and 4 in breadth, is supported upon 3 feet, each 12 inches long. In the upper flat surface of this machine holes or pits are formed to receive the larger pearls, the smaller ones being beat in with a little wooden hammer. The drilling instruments are spindles of various sizes, according to that of the pearls; they are turned round in a wooden head by means of a bow handle, to which they are attached. The pearls being placed in the pits which we have already mentioned, and the point of the spindle adjusted to them, the workman presses on the wooden head of the machine with his left hand, while his right is employed in turning round the bow handle. During the process of drilling he occasionally moistens the pearl by dipping the little finger of his right hand

(1) Dr. Faraday found that by first exhausting the lungs, by several deep exhalations, so as to expel the carbonic acid, and then taking a deep inspiration of fresh air, he was able to hold his breath for two minutes and a half.

in a cocoa-nut filled with water, which is placed by him for that purpose; this he does with a dexterity and quickness which scarcely impede the operation, and can only be acquired by much practice. They have also a variety of other instruments both for cutting and drilling the pearls. To clean, round, and polish them to that state in which we see them, a powder, made of the pearls themselves, is employed. These different operations in preparing the pearls occupy a great number of the black men in various parts of the island. In the black town or pettah of Columbo, in particular, many of them may every day be seen at this work, which is well worth the attention of any European who is not already acquainted with it."

PEARL, MOTHER OF. See MOTHER-OF-PEARL.

PEARLS, ARTIFICIAL. The art of making artificial pearls has been brought to such perfection in Paris, that even jewellers and pawnbrokers have occasionally had a difficulty in deciding between the artificial and the real. The origin of this successful imitation is given as follows:—A French bead maker named Jaquin, observing that when the small fish called *ablette*, or bleak (*Cyprinus alburnus*), was washed, the water was filled with fine silver-coloured particles, collected some of these for the purposes of his trade. He found that the soft shining powder thus obtained had to a remarkable degree the lustre of pearls; hence, he called it essence of pearl, or *essence d'orient*. He first made small beads of gypsum and covered them with this substance: they were greatly admired and eagerly sought after; but it was found that this pearly coat, when exposed to heat, separated itself from the bead, and attached itself to the skin of the wearer, in a manner that was anything but pleasant. The ladies themselves, it is said, suggested to Jaquin the making of hollow glass beads, and covering the inside with essence of pearl. This he did, and established a manufacture, of which some idea may be gained by the following account. Slender tubes of glass are first prepared, called *girasols*, a term applied to opal, and sometimes to the stone called cat's-eye, and given to these tubes because the glass is of a peculiar bluish tint. From these the artist blows minute globules, to the extent of from two to six thousand per day, not caring to make them all perfectly regular, or free from blemish, because the natural pearls are not so. The pearl essence is then mixed with a solution of isinglass, and is blown while hot into each bead by means of a fine glass pipe. The solution is spread equally over the whole internal surface, by shaking the pearls in a vessel placed over the table where the workman sits, and to which he gives motion by his foot. When the varnish is equally diffused and dry, the beads are filled with white wax; this gives them the necessary weight and solidity, and renders them less fragile. They are then bored with a needle, and threaded on strings for sale. The holes in the finer sort are lined with thin paper, that the thread may not adhere to the wax.

To produce one pound of scales no fewer than 4,000 fishes are required; but this quantity of scales only yields 4 ounces of pearl essence. The fish are about 4 inches long; they are sold at a cheap rate in the markets after being deprived of their scales. The value of a pound of washed scales in the Chalonnais is from 15 to 25 livres. The early manufacturers suffered great inconvenience from not knowing how to preserve the scales from putrefaction, and consequently being obliged to use the essence immediately it was obtained, lest it should acquire the intolerable odour of decayed fish. Attempts were made to preserve them in spirit of wine or brandy, but those liquors wholly destroyed their lustre. At length it was discovered that these fishy particles can be kept for a long time in solution of ammonia, and this enables the manufacturers of artificial pearls to carry on a considerable traffic with distant places where the fish is plentiful, the supply from the Seine, though abundant, being insufficient for the purposes of the trade of Paris. Down to a late period the heirs of M. Jaquin continued to manufacture pearls to a considerable extent, in the Rue de Petit Lion, at Paris. An elaborate account of this art is given by De Beost in a work entitled, "*L'Art d'imiter les Perles fines*," from which most English descriptions of this manufacture have been obtained.

PEARL ASH. See POTASSIUM.

PEARL WHITE. See BISMUTH.

PEAT. See FUEL, also INTRODUCTORY ESSAY, p. lxxxiv.

PECTINE (πηκτὶς, *coagulum*), the jelly of fruits, and distinguished from animal jelly in containing no nitrogen. The firm consistence of currant and other fruit jellies is due to this substance. It can be obtained from various fruits, by expressing their juice, and evaporating it at a temperature not exceeding 212°. "It may be obtained by the addition of alcohol to the recently-expressed juice of ripe currants or gooseberries: in the course of a few hours a gelatinous substance separates, which must be washed with weak alcohol and dried; it then resembles isinglass in appearance, and when digested in cold water, swells into a soft pulp, somewhat like starch: it is not blued by iodine. It may also be procured from the rasped roots of carrots and turnips." (*Brande.*) In contact with bases pectine becomes converted into *pectic acid*, but its acid properties are feeble, and its salts incapable of crystallizing. Pectine is said to contain $C_{16}H_{12}O_{16}$, and pectic acid $C_{16}H_{11}O_{15}$. Pectic acid has been recommended in France as part of the diet of invalids: it is also said to be an antidote in cases of poisoning by certain metallic salts, by forming insoluble compounds with their oxides. Pectic acid imparts a gelatinous character to soups prepared from roots which yield it.

PEDAL. See ORGAN.

PEDOMETER (ποῦς, a *foot*, and μέτρον, a measure); also called *perambulator*, *way-wiser*, *odometer*, or road-measurer; an instrument formed like a watch with a train of wheels arranged on the same plane: by means of a chain or string fastened to a man's

foot, or to the wheel of a carriage, the train advances a notch at each step, or at each turn of the carriage-wheel, and in this way the distance traversed is measured, and represented by a hand moving round a dial.

A form of perambulator often used on our public roads is represented in Fig. 1592. It consists of a

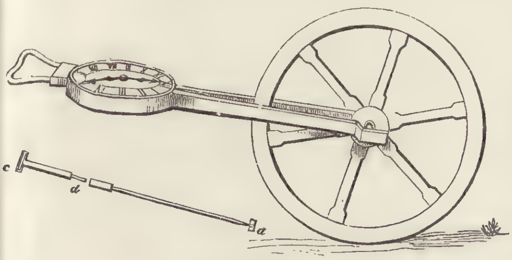


Fig. 1592.

wheel 2 feet $7\frac{1}{2}$ inches in diameter, so arranged that the circumference (8 feet 3 inches) shall be exactly equal to half a pole. On the end of the axis of the wheel is a nut $\frac{3}{4}$ inch in diameter, divided into 8 teeth, which, on moving the wheel round, fall into the 8 teeth of another nut *a* attached to one end of an iron rod, which is thus turned once round in one revolution of the wheel. This rod occupies a groove in the side of the frame, and at the other extremity of the rod is a square hole which receives the end *d* of a small cylinder *c d* placed under the dial-plate of a piece of mechanism at the end of the frame at *b*, so as to move about its axis. The end *c* is formed into a perpetual screw, which works into 32 teeth of a wheel arranged at right angles to it, so that when the instrument is driven forward, this index-wheel makes 1 revolution to 16 poles of distance traversed. On the axis of this wheel is a pinion with 6 teeth, which, working in another wheel of 60 teeth, carries the latter round once in a distance of 160 poles, or half a mile. This last wheel carries round with it a hand or index over the surface of a dial-plate, the outer rim of which is divided into 160 parts corresponding to the 160 poles. Also on the axis of the last-mentioned wheel is a pinion of 20 teeth, which, working into another wheel of 40 teeth, drives it round once in a mile. On the axis of this mile-wheel is a pinion of 6 teeth, which, working into a wheel of 72 teeth, causes the latter to rotate once in 12 miles. This last wheel carries an index-hand, which moves over the surface of the dial-plate, but its indications are measured by an inner graduated circle divided into 12 equal parts for miles, and each of these is subdivided for halves, quarters, and furlongs.

By varying the number of teeth in the pinions any standard of land-measure may be taken. If constructed with tolerable care this instrument affords pretty correct indications. Major Rennel states, that during the survey of India, he measured a meridian line of 3 degrees with this instrument, and found it to agree very closely with the measurement given by astronomical means.

The term *pedometer* is usually applied to instruments smaller than the above, such as can be worn on the person of a pedestrian for measuring the distance traversed on foot. Payne's pedometer is small enough to be worn in the waistcoat pocket, and is set going by the rising and falling of the body at each step in walking. The working parts of this instrument are shown in Figs. 1593, 1594, in a front and back view.

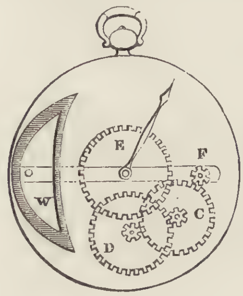


Fig. 1593.

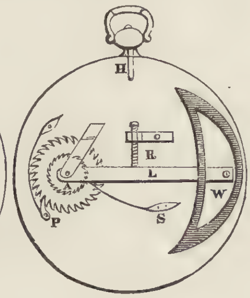


Fig. 1594.

L is a lever, adjusted so as to vibrate upwards and downwards at every step of the pedestrian. At one end of this lever is a weight W, and at the other a pivot X. Below the lever is a spring S, which keeps the lever when at rest close up to a regulating screw R; the screw and the spring being so adjusted as to be only just sufficient to overcome the weight of the lever, and to prevent it from falling downwards. The lever must be kept horizontal, for which purpose the instrument is hung in the waistcoat pocket by the hook H, and thus, every time the foot is placed on the ground preparatory to taking a new step, a slight jerk is produced, which causes the lever to sink a little, and the spring immediately returns it to its place. Thus it will be seen that the lever oscillates at every step, and these oscillations are made to act on an index hand by the following contrivance:—Fitted to the axis X of the lever, and moving with it, is a small ratchet-wheel A; beneath this is another and larger ratchet-wheel B fitting loose on the axis. These 2 wheels are connected together by a ratchet in such a manner, that when the lever falls both wheels are moved forward one or more teeth; but when the lever rises again by the force of the spring S, the larger ratchet-wheel B is held fast by the ratchet P. This wheel B is connected with the series of toothed wheels and pinions C D E, Fig. 1593, by means of a pinion F fixed in its under surface. The centre wheel E carries an index hand, which points to the figures on the dial-plate which indicate the number of miles passed over. This little instrument is usually made to register 10 miles, but by regulating the proportions of the wheels and pinions, it can be adjusted to any standard. By using an extra pinion and wheel, after the manner of the seconds-hand of a watch, and making the wheel with 10 times the number of teeth contained in the pinion, the instrument will be capable of registering 100 miles instead of 10. The mechanism of the pedometer may be combined with that of a watch, so that the pedestrian may compare the distance traversed with the time occupied.

In the museum of King's College, London, is a way-wiser, constructed by the Hon. Henry Cavendish. So lately as December 1851, a patent for an odometer was granted to Mr. W. Grayson. This apparatus consists of a train or system of wheelwork, enclosed in a box attached to one side of the carriage above the axle of the wheels. It is provided with two dials; one outside, for the use of the passenger or driver; the other inside, for the protection of the proprietor, and accessible only to him. The index hands of the two dials are connected by intermediate gearing, so as to act in unison; but the passenger index-hand is attached to a hollow shaft, fitting over its driving-spindle, and actuated by contact, to admit of the hand being set to zero, on the entrance of a passenger into the carriage, without deranging the apparatus. The apparatus is set in motion when the wheels of the carriage are revolving, by the intervention of a pendent lever, one end of which is acted on by a pin attached to the nave of one of the wheels, while the other end engages in a ratchet-wheel, forming part of the train of wheelwork, which it moves forward one tooth for every revolution of the wheels. The number of teeth on the ratchet-wheel will be determined by the size of the driving-wheels of the carriages, and apparatus may be adapted for use with driving-wheels of different diameters, by simply changing the ratchet-wheel.

PELTRY. See FUR.

PENS. The earliest pens, such as were used for writing on papyrus with a fluid ink, appear to have been made of reeds. In our translation of the Old and New Testaments, the word *pen* refers either to an iron *style* used with waxed tablets, or to a *reed*, quills not having been introduced earlier than the fifth century. It is uncertain what particular kind of reed was used for making pens, but it is described as a small, hard, round cane, about the size of a large swan's quill. The supply of these reeds was obtained from Egypt, Cairo in Asia Minor, and Armenia. Chardin and Tournefort describe a kind of reed used for pens in Persia. These reeds are collected near the shores of the Persian Gulf, whence they are sent to various parts of the East. After being cut, they are deposited for some months under a dunghill, when they assume a mixed black and yellow colour, acquire a fine polish and a considerable degree of hardness, and the internal pith dries up into a membrane which is easily detached. Reed pens are still in use, and they suit the Arabic character better than quill pens. The Arab, in writing, places the paper upon his knee, or upon the palm of his left hand, or upon a dozen or more pieces of paper attached together at the 4 corners, and resembling a thin book, which he rests on his knee. The ink is very thick and gummy.

The quills used for pens are chiefly from the goose, the swan, and the crow; but the ostrich, turkey, and other birds occasionally contribute. The general use of steel pens has greatly lessened the demand for quills; but it appears, that in the year 1840, when the import duty on goose-quills was 2*s*. 6*d*. per 1,000, as many as 22,024,000 quills had been entered for home consumption in that year. In 1842 the duty was reduced to 6*d*. per 1,000. Most of the goose-quills are from the Netherlands and Germany, Russia and Poland. In the two latter countries vast flocks of geese were maintained for the sake of their quills. When the demand was large, this country has received from St. Petersburgh alone as many as 27,000,000 quills in one year. Some idea of the number of geese required to keep up such a supply may be judged of from the fact, that each wing produces about 5 good quills, and that by proper management a goose may afford 20 quills during the year. Quills are classified according to the order in which they are fixed in the wing, the second and third quills being the best. The goodness of quills is estimated partly by the size of the barrel, but more by the weight; hence the denomination of quills of 14, 15, &c. loths per *mille*, the mille consisting of 1,200 quills.

The quills as they come from the bird are covered with a membrane, and are tough and soft, so that they will not make a clean slit: they are also opaque, and the vascular membrane adheres strongly to the interior surface of the barrel. These defects are got rid of, and the quills prepared for the pen-maker, by the operations of *quill-dressing* or *quill-dutching*. The quills are first sorted, according to the length and thickness of the barrel, into *primes*, *seconds*, and *pinions*. They are then *clarified* by the removal of the membranous skin, for which purpose they are plunged for a short time into hot sand, the heat causing the outer skin to crack and peel off, its removal being facilitated by scraping with a sharp instrument: at the same time the internal membrane becomes shrivelled up and falls down towards the point of the quill. The effect of the heat is also to consume or dry up the oily matter of the quill, and thus to render the barrel transparent. This process, which may be repeated several times, is called *dutching*, probably from the circumstance of its having been first adopted in Holland. The heat requires regulation, or the barrel will be injured; but the effect of the process is to give to the barrels the colour of fine thin horn, or an impure white. In some cases a uniform yellow colour is produced by dipping the barrels in dilute nitric acid. This process hardens them. Quills may also be hardened by steeping for a few minutes in alum-water at a boiling temperature. The quills having been dressed and finished, a portion of the barb is stripped off so as to occupy less room in packing, and the quills are tied up in bundles of 25 or 50 each for the market.

A different mode of preparing the quills is adopted by some dressers. The quills are first moistened, not by immersion, but by dipping their extremities into water, and allowing the moisture to be absorbed by capillary attraction. They are then heated in the fire or over a charcoal chauffer, and next passed quickly under an instrument with a fine edge, which flattens them, and apparently spoils them: they are again scraped and exposed to heat, whereby they assume their original form. It is a remarkable fact,

that, after crushing a feather in this way, it may be restored by exposure to steam or a moderate heat.

The quills, having been prepared, are cut into pens by the pen-cutter's knife, and are also trimmed. A pen-cutter will cut in a day two-thirds of a long thousand (1,200). Some years ago, a house in Shoe-lane cut about 6,000,000 pens yearly.

Crow-quills are usually employed in fine drawings, on account of the fine point to which they can be brought. They are useful in that laborious kind of etching intended to imitate prints.

Before steel pens became common, a number of pens were cut out of the barrel of a quill just as they are now cut out of sheet steel. The narrow end, and also the stalk of the quill, having been cut off, a cylinder was passed through the barrel and 2 cutting-edges passed along it, 1 on each side, whereby the quill was separated into 2 semi-cylinders. These pieces were then placed in a groove with the convex side undermost, and the edges smoothed with a plane. Each half cylinder was then cut into 3 or 4 pieces, and each piece operated on by a small cutting-press or *nibbing-machine.* A few strokes with a pen-knife then gave the form of a pen to each piece, and being fixed in a handle, was fit for use.

From the softening of the quill pen by the ink, and the wear of the points by friction, frequent mending was required, or very bad writing was the result. The first attempts to render pens more permanent consisted in arming the nibs with metallic points. Pens were also constructed of horn, tortoise and other shells, and also of glass. Nibs have also been formed of precious stones. In 1823 Messrs. Hawkins and Mordan employed horn and tortoise-shell cut into nibs, softened in boiling water, and small pieces of diamond, ruby, &c. imbedded into them by pressure. Thin pieces of gold or other metal have also been attached to tortoise-shell. In Mr. Doughty's pens the nibs were rubies set in fine gold: these pens were very durable, and the writing always uniform in character. To prevent the points being injured by contact with hard substances, the inkstand is to be lined with Indian-rubber. Dr. Wollaston also constructed pens with two flat slips of gold placed angularly side by side, and tipped with rhodium. In the Great Exhibition, Messrs. Wiley of Birmingham exhibited specimens of gold, palladium, gold and silver, and silver pens, pointed with the native alloys of iridium and osmium. Such pens not being acted on by the ink, are almost indestructible by ordinary usage.

The permanent pens above alluded to were costly, or deficient in elasticity, or easily liable to injury. Additional elasticity was obtained by springs on the backs of the pens, made to slide backwards and forwards, so as to vary the elasticity: but it was found that the drying of the ink in the pen greatly interfered with the action of the spring.

The first notice that we find of steel pens for writing is in 1803, when Mr. Wise constructed barrel-pens of that metal mounted in a bone case for carrying in the pocket. These pens were costly, and not very successful. This form of pen, as improved by Mr. Gillott of Birmingham, was for many years in request. In the improved pen, metal of better quality thinner and more elastic, was employed: the slit was made shorter, and the finish and temper of the metal more carefully attended to. At the same time such was the reduction in price that a gross of pens was sold for little more than what was charged for one of Wise's pens. We are not aware whether Mr. Gillott or Mr. Perry was the first to introduce the improvements which led to the present form and make of steel pens. Both gentlemen, the latter especially, have taken out a number of patents for their pens, and have advertised them extensively for many years. In 1831 Messrs. Mordan and Brockedon brought out an *oblique* pen, in which the slit was inclined at an angle of 35° to the general direction of the pen, the oblique position in which an ordinary pen is usually held suggesting the change. Then there were *lunar* pens, in which the under surface was large and concave, so as to hold a good deal of ink. Mr. Gowland invented a pen with an additional nib, called the *three-nibbed slit* pen. A large number of other forms have also been introduced, and have had their brief periods of existence. The ordinary form of steel pen, resembling that of the common quill pen, has long and deservedly maintained its ground, and still continues to be manufactured in vast numbers.

Birmingham is the chief seat of this manufacture. The steel for making pens is rolled for the purpose at Sheffield into thin sheets, and these are cut into slips about 4 inches broad and 3 feet long, then annealed, the scales removed by pickling in dilute sulphuric acid, after which the strips are again rolled to the required thickness. From these strips *blanks* or *flats* are cut out by girls, by means of a bed and punch, much in the same way as blanks for buttons, [see BUTTON;] care being taken that the fibres of the steel run in the direction of the length of the pen. The next operation is to pierce the hole which terminates the slit, and remove any superfluous steel which is likely to interfere with the elasticity of the pen. The blanks are then annealed in large quantities in a muffle, after which the maker's name, &c., is stamped upon each blank by means of a small punch. The blanks are still flat pieces of steel. They are now transferred to another class of workers, who by means of a press make each piece concave for nib-pens, and form the barrel for barrel-pens. The pens are enclosed in an iron box, and heated in a muffle, and when of a uniform red heat, they are hardened by being plunged into oil. The adhering oil is removed by agitation in a tin-plate barrel. They are next tempered, and lastly placed in a revolving cylinder with sand, pounded crucible, or other cutting material, which brightens them to the natural colour of the steel. The nib is next ground with great rapidity by a girl, who picks up each pen, places it in a pair of plyers of the proper form, and finishes it with a single touch on a small emery wheel. After this the slit is made by means of a chisel or wedge with a flat side fixed to the bed of a press, the descending screw of which has also a chisel or cutter, which very accurately corresponds

with the former. After the slits are made, the pens are coloured brown or blue by placing them in a revolving metal cylinder over a charcoal stove, and removing them the moment the film of oxide of the desired colour is formed. The pens are lastly immersed in a solution of lac in naphtha, which imparts brilliancy after they are dried by heat. The pens are then counted and made up in boxes.

There was a large display of steel and other pens in the Great Exhibition, among which those by Mr. Gillott were conspicuous. It is stated in the Illustrated Catalogue that this exhibitor employs upwards of 500 persons, of which four-fifths are women, skilled workmen being employed to repair and set the tools. Mr. Gillott's annual production of pens is said to exceed 150 millions. Messrs. Hincks, Wells and Co. of Birmingham exhibited specimens of *Lilliputian* pens, intended to show the skill of the tool cutter, and the perfection of the machinery employed. A gross of the smallest weighed less than 34 grains, and could be contained in a Barcelona nutshell.

PENCIL. See Black-Lead.

PENDULUM. See Horology.

PEPPER, the dried fruit of a climbing plant (*Piper nigrum*) extensively cultivated throughout a wide range of countries in the East, including Sumatra, Borneo, the Malay Peninsula, and all countries to the east of the Gulf of Siam. The berries grow in long thin clusters, and are gathered while yet green or when only a few are beginning to turn red. They are quickly dried on mats in the sun, and become the shrivelled black pepper as we receive it in this country. White pepper is the same fruit freed from the outer rind by macerating in water.

The pepper gardens of the East are marked out in a square or oblong form, and planted in even rows, running parallel and at right angles with each other. The intersections forming the intervals between the plants are at the distance of 6 feet from each other. The usual mode of propagating the pepper, is by cuttings, a foot or two long, taken from the horizontal shoots that run along the ground from the old vines. With the cuttings of the pepper plant are also inserted cuttings of a rapidly growing tree, which is to serve as its support. Several kinds of tree are employed for this purpose. The number of plants in a Sumatran pepper ground is from five hundred to a thousand, but occasionally gardens of two or three thousand vines are heard of. The pepper does not show blossom till the third year, and in the rainy season which succeeds the first appearance of the fruit the whole plant is loosened from its support, and turned down again into the earth with only a small shoot left aboveground. This, however, grows more vigorously than ever, re-ascending the prop in one season to the height of 8 or 10 feet, and bearing a full crop. This increases every year to the seventh or eighth, when the vine is at its best condition, and continues in that state for about 4 years, when it gradually declines. On the first appearance of the decline of one pepper garden, another is immediately planted, to allow time for the second to come into bearing before the first has ceased to yield a remunerative supply. Pepper grounds are usually on the level banks of streams, and the produce is conveyed on rafts to its destination.

The analysis of black pepper gives soft resin, a volatile oil, piperine, extractive gum, bassorine, malic and tartaric acids, salts, &c., the odour being apparently due to the volatile oil, which is not acrid, and the pungent taste to the resin. Piperine is an inodorous and tasteless substance, discovered by Oersted, in black pepper. It is extracted by digesting 16 oz. of coarsely-powdered pepper for 48 hours in twice its weight of water, 5 times in succession; then pressing out and drying the insoluble portion, and digesting it for 3 days in 24 ounces of alcohol. This solution is then pressed out, filtered and evaporated to the consistence of syrup; crystals are deposited, which are freed from adhering resin by ether redissolved in alcohol, purified by animal charcoal, and recrystallized.

PEPPERMINT (*mentha piperita*), a plant common in many parts of Britain, but cultivated for the sake of its volatile oil. The plant when dried is more powerful than in the fresh state; it is of a lively green, with a peculiar aromatic odour, and a pleasant taste, resembling camphor, burning at first, but afterwards leaving an enduring sensation of cold in the mouth. The dried herb is used for preparing a distilled water as well as the volatile oil. The oil is obtained by distilling the herb with water. It is of a pale yellow or greenish yellow tint, which in some cases deepens by age. It has a strong odour of the plant, and a hot aromatic taste succeeded by coldness on the tongue. Three varieties of the oil occur in commerce, the *German, English,* and *American.* 20 lbs. of the herb yield from 4 to 6 drachms of oil, but if the flowers be also distilled, (which is done in obtaining the American oil,) 4 ounces may be obtained. The American oil is more soluble in alcohol than the German: its sp. gr. is 0·92, but when rectified 0·90. The last portions which pass over during the rectification, deposit on being cooled a concrete substance, *stearoptene,* also called *peppermint camphor;* it forms colourless prismatic crystals, having the odour and taste of peppermint; it is almost insoluble in water, but very soluble in alcohol and ether: it fuses at about 92°, and boils at 415°; the density of its vapour is 5·45, and its formula $C_{20}H_{20}O_2$.

Oil of peppermint is stimulant and antispasmodic. It is often adulterated with oil of turpentine, oil of marjoram, and alcohol.

PERAMBULATOR. See Pedometer.

PERCUSSION CAPS. Considerable doubt exists as to who was the inventor of percussion caps in their present simple and effective form. It appears that in the year 1807 the Rev. Mr. Forsyth obtained a patent for the use of fulminating powder in firing artillery. The powder employed by him consisted of chlorate of potash, sulphur, and charcoal,[1] and

(1) The following ingredients and proportions have been recommended :—Chlorate of potash, 6 parts; sulphur, 3; powdered

the apparatus for using it consisted of a magazine turning on a roller or tube screwed into the breeching of the gun. A small portion of fulminating powder being deposited in the roller, the magazine was restored to its firing position, and the cock struck on a pin with a spiral spring attached to it, which inflamed the gunpowder. This contrivance passed through a great variety of forms before the percussion cap was invented. According to Mr. Wilkinson, this invention was purchased by Mr. Egg from Mr. Roantree, a gun-maker at Barnard Castle, Durham, who had it from a workman employed by Mr. Joseph Shaw, an English landscape painter, afterwards resident in America. Mr. Shaw assured Mr. Wilkinson that in 1814 he invented a steel cap, which, when fired, was retained to be primed again; in 1815 he invented a pewter cap, which was thrown away after using; and in 1816, the copper cap similar to that now in use.

Percussion caps are produced by pressure: the blanks are punched out of thin rolled copper in the form of a cross, with short equal arms, or with only 3 arms, and the blanks having been annealed, are formed into caps by means of dies which fold up the arms and unite them into a short tube, while the central part of the metal which forms the top of the cap, sustains the blow of the hammer. The bottom of the cap is touched with a solution of gum or glue into which the fulminating powder is dropped. Caps are sometimes varnished to prevent them from losing their power by exposure to damp. An exhibitor of percussion caps in the Great Exhibition calculated, we know not upon what data, that the total manufacture of percussion caps for sporting guns in Europe, may be estimated at 1,300 millions yearly, requiring 396,000 lbs. weight of copper. Caps for the use of the army are formed at Woolwich by very ingenious machinery.

PERCUSSION, CENTRE OF. See CENTRE.

PERUVIAN BARK. See BARK—QUININE.

PETROLEUM. See ASPHALTUM.

PEWTER. Common pewter is an alloy of about 80 parts of tin and 20 of lead; but other metals, such as copper, antimony, and zinc, are sometimes added. The manufacturers of pewter consider that a better alloy is obtained by melting up old pewter with new ingredients, so that the composition of pewter cannot even be said to be known to the makers. The Pewterers' Company[1] in 1772 attempted to regulate the quality of pewter wares by establishing "a table of the assays of metal and of the weights and dimensions of the several sorts of pewter wares." Persons who departed from the regulations were liable to expulsion from the guild, but they have been so generally disregarded as to have had very little effect in keeping up a standard of pewter. The assay was directed to be made by casting a small button of the metal, to be tried in a brass mould so proportioned that such a button of pure tin would weigh exactly 182 grains. All the metals added to the tin being heavier than tin, the buttons are heavier the less tin they contain. The following scale is founded on these data:—

Assay of pure tin	182 grains.
Ditto of *fine* or *plate* metal $1\frac{1}{2}$ grains heavier than tin, or	$183\frac{1}{2}$,,
Ditto of *trifling* metal $3\frac{1}{2}$ grains heavier than tin, or........................	$185\frac{1}{2}$,,
Ditto of ley metal $16\frac{1}{2}$ grains heavier than tin, or........................	$198\frac{1}{2}$,,

Equal parts tin and lead are about 50 grains heavier than tin, or 232 grains. "Some pewters are now made nearly as common as the last proportion: when cast they are black, shining, and soft; when turned, dull and bluish. Other pewters only contain $\frac{1}{5}$ or $\frac{1}{6}$ of lead: these, when cast, are white, without gloss, and hard; such are pronounced very good metal, and are but little darker than tin. The French legislature sanctions the employment of 18 per cent. of lead with 82 of tin as quite harmless in vessels for wine and vinegar.[2] The finest pewter frequently called *tin and temper*, consists mostly of tin, with a very little copper, which makes it hard and somewhat sonorous, but the pewter becomes brown coloured when the copper is in excess. The copper is melted, and twice its weight of tin is added to it, and from about $\frac{1}{2}$ to 7 lbs. of this alloy, or the *temper*, are added to every block of tin weighing from 360 to 390 lbs.[3] Antimony is said to harden tin, and to preserve a more silvery colour, but is little used in pewter. Zinc is employed to cleanse the metal rather than as an ingredient. Some stir the fluid pewter with a thin strip, half zinc and half tin; others allow a small lump of zinc to float on the surface of the fluid metal, while they are casting, to lessen the oxidation."—*Holtzapffel.*

Of the three ordinary sorts of pewter above distinguished, *plate* pewter is the hardest, and is used for making plates and dishes. The pewter named trifle, is used for beer pots; and ley for the larger wine measures. Plate pewter has a bright silvery lustre when polished; and according to Dr. Ure, the best is composed of 100 parts tin, 8 antimony, 2 bismuth, and 2 of copper. Trifle, 83 of tin, and 17 of antimony, but it usually contains a good deal of lead.

Pewter wares are formed either by hammering or by casting; plates and dishes being hammered, and measures and spoons cast. In soldering together

glass, 1 part; powdered charcoal, $\frac{1}{2}$ a part. Or, chlorate potash, 5 parts; sulphur, 2 parts; charcoal, $\frac{1}{2}$ a part; with from $\frac{1}{3}$ to $\frac{1}{2}$ the weight of fulminating mercury. It must be remembered that chlorate of potash is dangerously explosive when rubbed with sulphur. The fulminating mercury composition for caps is fulminating mercury, 3 parts; chlorate potash, 5; sulphur, 1 part; powdered glass, 1 part.

(1) The Pewterers of England have formed an incorporated society ever since the reign of Edward IV. (1474.) By act of parliament 25 Henry VIII. their wardens had the inspection of pewter throughout England.

(2) A table of specific gravities was published for the purpose of testing the quality of the alloy, the density of which, at the legal standard, is 7·764. An excess of lead is at once detected by an increased density.

(3) As the copper is much more difficult of fusion than the tin, it is necessary, in order to cause the two metals to combine properly, to melt the $\frac{1}{2}$ or 1 per cent. of copper, in a crucible, and to add it to two or three times its weight of melted tin: this forms the alloy called *temper*. It may be fused in a ladle, and added in small quantities to the tin, or to the fluid pewter, until the proper proportions are attained.

the various parts of pewter articles with soft solder, a blast of hot air from a small charcoal furnace affords sufficient heat. [See SOLDERING.] Pewter is also made in the form of sheets, for engraving cheap music, the softness of the metal allowing the notes to be formed by means of punches, instead of the more elegant, accurate, but slower method of engraving with a burin.

Pewter wares are seldom polished, but when finished by the turning tool or scraper, are burnished with oil, which is removed with a rag and whiting. Pewter vessels are best cleaned by means of silver sand and water, or with solutions of potash or soda to remove the grease.

Lapidaries, jewellers, watchmakers, &c., use laps and polishers of pewter.

PHARMACY (φαρμάσσειν, *medicari*), the application of chemistry to the manufacture, preparation, and mixing of drugs and medicines.

PHAROS. See LIGHTHOUSE.

PHOSPHORUS derives its name from its property of shining in the dark (φῶς, *light*, and φέρειν, to bear). It is an important elementary substance (P 32), and is found in the three kingdoms of nature, chiefly in the form of phosphoric acid united with various bases. In this state it occurs in the ancient unstratified rocks, and in modern lavas. As these crumble down into fertile soil, the phosphates are taken up by plants, and are thus introduced as food into the bodies of animals. The earthy phosphates communicate stiffness and inflexibility to the bones of animals, and are of great importance in the animal economy.

Phosphorus was discovered in 1669, by Brandt, a merchant of Hamburg, while attempting to obtain from urine a liquid capable of transmuting silver into gold. Kunckel, a German chemist, detected the source of the new substance, informed Kraff of Dresden thereof, and he proceeded to Hamburg to learn the details of the process for which he paid 200 dollars. In the meantime, however, Kunckel had prepared and described phosphorus. In 1680 it was noticed in the Philosophical Transactions of the Royal Society of London; and it was soon after prepared in considerable quantities by Hankwitz, under the direction of Boyle, as noticed in our article MATCHES. In 1737, the French Government purchased and published a method of preparing phosphorus from urine, by which it appears that 5 hogsheads of that liquid yielded only 4 ounces of phosphorus. This disgusting process was abandoned when it was discovered that phosphorus enters into the composition of bones. A method was therefore contrived and perfected by various chemists of eminence, for obtaining phosphorus in large quantities from bones. The following is a sketch of the process actually adopted.

The bones are carefully calcined in contact with air, in which operation the organic portions are destroyed, and escape in the form of gaseous products. The *bone earth* which remains is a mixture of superphosphate of lime, and carbonate of lime. It yields about 13 or 14 per cent. of phosphorus, but probably contains as much as 17. To every 3 parts by weight of this bone earth are added 2 parts of sulphuric acid, and 15 to 20 of water; the whole is well stirred up, and left for 24 hours. The sulphuric acid decomposes the carbonate of lime, forms a solid sulphate of lime therewith, and disengages the carbonic acid. The sulphuric acid also acts on the superphosphate of lime, but does not entirely decompose it: it takes up from it a portion of lime, and leaves the phosphate in the state of an acid phosphate of lime, very soluble in water, while the sulphate of lime is scarcely soluble at all. The two salts are separated by pouring the whole into a conical linen bag of close texture, which retains the sulphate of lime, and allows the solution of acid phosphate to pass through. The mass is pressed, to free it more completely of the soluble portion. The filtered solution is evaporated in a copper boiler to the consistence of a syrup; powdered charcoal is then added in small portions, and the mass after being evaporated to dryness, is further dried at a red heat. This substance is put into an earthen retort, coated with luting on the outside, to defend it from the too fierce action of the fire. The neck of the retort fits into the tubulure of a copper receiver half filled with water, and furnished with a tube for the escape of the gas formed during the distillation. In operating on the large scale, a number of these retorts are arranged side by side, in a reverberatory furnace. Each retort has its own receiver, and all the receivers stand in a trough filled with water, at the temperature of about 110°, and kept at that temperature in order that the phosphorus in distilling over, may not solidify and obstruct the tubulure. The superphosphate of lime, although dried at a high temperature, retains chemically combined water, which is liberated by the superior heat of the furnace; and at the moment of being set free, coming in contact with the incandescent carbon, is decomposed, producing hydrogen gas and carbonic oxide. The superphosphate of lime is decomposed into basic phosphate of lime, which remains unchanged; and phosphoric acid, which, in contact with the incandescent carbon, yields phosphorus, carbonic oxide, and phosphuretted hydrogen, the last inflaming spontaneously on passing into the air. The phosphorus distils over, and condenses in the liquid form in the tubulure, and there remains in the retort sub-phosphate of lime and charcoal which was in the first instance added in excess. The phosphorus is purified by being forced through chamois leather, and is cast into sticks for sale by one of the methods hereafter described. Phosphorus may also be further purified by distillation.

There are other methods of procuring phosphorus from bones. One method, by Wöhler, is to calcine two parts of ivory-black (which is a mixture of phosphate of lime and charcoal) with one of fine quartzy sand, and a little ordinary charcoal in cylinders of fine clay, at a very high temperature. Each cylinder is fitted with a bent copper tube, one branch of which descends into a vessel of water. In this process the

silica acts as an acid, and combines with the lime of the phosphate at a high temperature; while the liberated phosphoric acid is decomposed by the carbon. We are, however, assured by an experienced chemist that this process cannot be pushed to completion, as the retort melts at the needful heat before the phosphorus has distilled over.

Pure phosphorus at ordinary temperatures resembles wax, and like it is soft and flexible; at the temperature of 32° it is hard and brittle. Its density is 1·77, and that of its vapour 4·326, air being unity. It melts at 108°, and boils at 550°. It is not soluble in water, and hence, on account of its great inflammability, it is preserved under that fluid. It dissolves sparingly in absolute alcohol, in ether, oils, naphtha, and most of the liquid hydrocarbons, and abundantly in sulphuret of carbon. By evaporating a solution of phosphorus in the last-named substance, it may be obtained in rhombic dodecahedrons. By exposure to light, even under water, it loses its transparency, and becomes yellowish; so that the bottle containing it is usually kept in a case of tinned iron, for the sake of opacity as well as security. By exposure to the direct rays of the sun it becomes red, even in vacuo; which proves that the change is merely molecular, and not due to chemical combination. If heated to 140° and suddenly cooled, it sometimes turns black.

Phosphorus has so great an affinity for oxygen, that by simple exposure to the air at ordinary temperatures, it undergoes a slow combustion, exhaling a vapour, luminous in the dark, and having an odour resembling garlic. The luminousness of phosphorus is so excellent a test of its presence, that if a very minute proportion be dissolved in sulphuret of carbon, and a drop of the solution be placed on a hot plate in the dark, the presence of $\frac{1}{12000}$th part of phosphorus is readily detected. A stick of phosphorus if exposed for a sufficient length of time, entirely disappears in this vapour. The absorption of oxygen during the process may be proved by floating a small dish containing phosphorus on water, and covering it with a bell-glass. The oxygen will gradually disappear, and water will rise in the glass to take its place. Indeed, this is one of the methods of determining the quantity of oxygen in air or other gaseous mixture, the glass standing over mercury instead of water. [See Eudiometer.] It appears, however, that in oxygen gas there is little or no absorption at temperatures below 80°, but if the pressure be diminished to $\frac{1}{8}$th, or $\frac{1}{10}$th of that of the atmosphere, the phosphorus will immediately become luminous in the dark, and oxygen be absorbed. Or if the density of the oxygen be reduced by mixing it with nitrogen, hydrogen, or carbonic acid, the phosphorus becomes luminous. The slow combustion of phosphorus is also prevented by minute portions of certain gases and vapours in the volume of confined air. Thus at 66° 1 volume of olefiant gas in 450 volumes of air; 1 of ether vapour in 150 volumes of air; 1 of naphtha vapour in 1820, and 1 of vapour of turpentine in 4444 volumes of air, prevented the slow combustion of the phosphorus. Even at much higher temperatures a certain proportion of these vapours prevented the effect; but on diminishing the pressure the phosphorus became luminous. Professor Graham, to whom these experiments are due, supposes that the gases and vapours in question are themselves undergoing a slow oxidation, for when 2 oxidizable bodies are in contact, one of them often takes precedence in combining with oxygen to the entire exclusion of the other.

When phosphorus is heated to about 140° it takes fire, if perfectly dry it will ignite at a very much lower temperature by mere exposure; a moderate friction is also sufficient for the purpose, and it will even take fire if left on a woollen cloth or other badly conducting substance. The ease with which it ignites by gentle friction, makes it dangerous to handle except under water. When it comes in contact with the hands in an ignited state, it produces deep and dangerous wounds, which are long and difficult to heal. When the phosphorus burns with flame in oxygen or atmospheric air, the product of combustion is a white deliquescent powder, which is *phosphoric acid*, PO_5; but when the phosphorus undergoes slow combustion in contact with air at the ordinary temperature, it undergoes a lower degree of oxidation and forms *phosphorous acid* PO_3. In addition to these compounds of phosphorus and oxygen there are two others:—*oxide of phosphorus* P_2O, and *hypophosphorous acid* PO.

The *oxide of phosphorus* may be formed by directing a stream of oxygen gas upon phosphorus, melted below the surface of hot water. Vivid combustion ensues, and the phosphorus is converted into phosphoric acid and a red pulverulent oxide.[1] When pure this oxide is a red or yellow powder, according to its state of division. It is insoluble in water, ether, alcohol, or oils, and is decomposed by heat into phosphorus and phosphoric acid.

Hypophosphorous acid is one of the substances formed when phosphuret of calcium [See Lime] or of barium is thrown into water. A portion of the water is decomposed, forming phosphuretted hydrogen PH_3 (which rising in bubbles to the surface, ignites on coming in contact with the air, forming beautiful rings of phosphoric acid, which float away, expanding until they disappear) phosphoric acid, hypophosphorous acid and lime, or baryta. The soluble hypophosphite is separated by filtration from the insoluble phosphate, and on precipitating the base by the addition of sulphuric acid, the hypophosphorous acid is obtained in solution, and may be reduced to the consistence of a syrup by evaporation. This acid is a powerful deoxidizing agent; it forms with bases *hypophosphites* which are soluble in water, and mostly deliquescent and uncrystallizable.

Phosphorous acid is formed as already noticed, by the slow combustion of phosphorus in the air, or

(1) Schrötter insists that there is no oxide of phosphorus; he would call this red powder, amorphous phosphorous.

by burning it by means of a very limited supply of air, when it forms an anhydrous white powder. The hydrated acid may be formed by adding water to the terchloride of phosphorus, in which case the oxygen of the water passes over to the phosphorus, forming phosphorous acid, and its hydrogen to the chlorine, forming hydrochloric acid, which may be expelled by heat, and the residue crystallizes on cooling. Phosphorous acid dissolves rapidly in water; it has a sour taste, and forms with certain bases a class of salts termed *phosphites*.

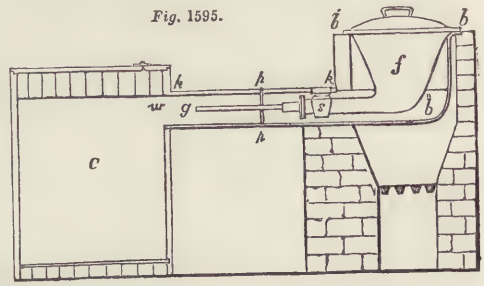
Phosphoric acid is formed by burning phosphorus in a vessel supplied with dry air; the anhydrous acid forms in white snow-like flakes, which have a strong attraction for moisture, deliquescing immediately on exposure to air, and when thrown into water combining with it with a hissing noise. The water cannot be expelled from the hydrate. Phosphorus may also be oxidized to its maximum by heating it in nitric acid; but the action is very violent and requires caution, except when amorphous phosphorus is used, when there is no difficulty. By distilling off the greater part of the acid, and heating the residue in a platinum vessel, the hydrated acid may be obtained pure, forming what is termed *glacial* phosphoric acid, from its resemblance to glass. Phosphoric acid may also be prepared from the acid phosphate of lime produced by the action of sulphuric acid on bone earth. The phosphoric acid is precipitated by carbonate of ammonia, the insoluble lime salt is separated by filtration, and the filtered liquid containing phosphate and sulphate of ammonia is evaporated and ignited in a platinum crucible; hydrated phosphoric acid alone remains.

Phosphoric acid is a powerful and intensely sour acid: it forms with bases an important class of salts termed *phosphates*. This acid and its compounds are of great interest to the chemist, from the remarkable changes which they undergo by the action of heat.

We now return to the subject of phosphorus, for which there is an enormous demand for the manufacture of lucifer matches [see MATCHES], and such has been the effect of this demand on the price, that it is now supplied wholesale under *three shillings* per pound; whereas, the manufacturer who first supplied it to the London makers of matches, and who is now living, obtained *four guineas* per pound for it. Some calculations as to the actual quantity consumed in England in this manufacture will be given further on.

We have already stated that phosphorus is sent into the market in the form of sticks; in its fused state it is moulded to this form by being poured into glass tubes, and when solid forced out by means of wires. A better method has been contrived by Herr Shubert. In his apparatus the melted phosphorus is made to flow from a copper receiver into horizontal glass tubes, one extremity of each tube being surrounded by water heated above 111° Fahr. and the other extremity by cold water. The phosphorus when solid is removed from the tube, and thus leaves space for a fresh supply. The apparatus consists of a small copper boiler *b*, Fig. 1595, mounted in brick work, and heated from below. On one side is a horizontal

Fig. 1595.



canal *k*, also of copper, but open at the top, the further extremity of which opens into a cistern c; the canal is divided into two compartments by a movable partition *p*, through which the moulding tubes pass. The boiler contains a second vessel of tinned copper *f*, funnel-shaped, with a horizontal tube furnished with a metal stop-cock *s*, the horizontal section of which is shown in Fig. 1596. A copper plate *p p* is screwed tightly on the wide aperture of the cock *o o;* it has 2 perforations to receive the copper tubes *t t*, which are about 2 inches in length, and into which glass tubes *g* about 1 foot in length are inserted. The cistern c receives the sticks of phosphorus when formed, and is furnished with a cover to exclude the light.

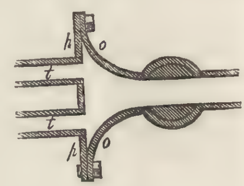


Fig. 1596.

In making the sticks the cock *s* is closed, and the vessel *f* filled with water. Pieces of phosphorus are then put in, and these are melted by heating the water bath *b*. The operator sits in the space between the cistern and the wall, and by suddenly opening and closing the cock, a small quantity of phosphorus passes through the glass tubes into the cold water *w*, and closes them. The rough piece of phosphorus which projects into the water from the ends of the tubes is used as a handle for drawing out the sticks. The cock may now be left open, and the phosphorus drawn alternately from either tube, being from time to time cut off with a strong pair of scissors and allowed to fall into the cistern. In this way from 15 to 20 lbs. of phosphorus may be moulded into sticks in less than a quarter of an hour.[1] If the phosphorus is pure it may be very possible to draw it out in a continuous stick by machinery.

In our INTRODUCTORY ESSAY, p. cxxxviii, is a short notice of a remarkable form of phosphorus discovered by Schrötter, of Vienna, and known as *allotropic* or *red* phosphorus,[2] which is as remarkable for negative properties as the common phosphorus is for positive ones. We also stated in our article MATCHES the desirability of introducing this new form of phosphorus

(1) Annalen der Chimie und Pharmacie, quoted in the Pharmaceutical Journal, vol. iv.

(2) Professor Schrötter's Memoir on this subject will be found in the Annales de Chimie, vol. xxiv. New Series.

into the manufacture. It is now our duty to examine this subject in detail, and we propose to state *first*, the method of producing red phosphorus in large quantities, and *secondly*, its claims to supersede common phosphorus in the making of matches.

In July, 1851, a patent was granted to Arthur Albright, of Birmingham, for "Improvements in the Manufacture of Phosphorus and in the Apparatus to be used therein," the invention of Professor Anton Schrötter, of Vienna; and from the specification dated 16th January, 1852, we obtain the following particulars:—

The invention consists in a mode of producing phosphorus in an amorphous or non-crystalline state, differing both in its nature and properties from the ordinary phosphorus of commerce. The latter is crystalline in formation, of a pale yellow colour, approaching, when pure, to a white, nearly transparent, luminous in the dark, and burning in the open air at a temperature of about 148° Fah. The amorphous phosphorus, on the contrary, is opaque, of a varying red colour, is not luminous in the dark, does not take fire when exposed to an ordinary atmosphere, nor even by friction or percussion, unless the temperature produced thereby exceed 464° Fah., the ordinary temperature at which this amorphous phosphorus is inflammable being about 482° Fah., but when combined with chlorate of potass or other appropriate materials, it inflames with great energy, and may therefore be used in the manufacture of lucifer matches and other instantaneous igniters. It is, moreover, free from those pernicious qualities which render the application of ordinary phosphorus to these last-named purposes so dangerous to health. In a commercial point of view the amorphous phosphorus possesses a great advantage over the crystalline, inasmuch as the former may be transported with perfect safety, while the carriage of the ordinary phosphorus is attended with considerable trouble and risk, and consequent expense. By this conversion of condition the phosphorus is deprived of its poisonous quality, and of much of the peculiar and unpleasant smell which arises from the common article, neither is it so liable in warm temperatures to become converted into phosphoric acid.

Ordinary manufactured phosphorus is used for conversion into the new state, and the apparatus employed for the purpose is represented in vertical section Fig. 1597, and in plan Fig. 1598. A A is a cast-iron vessel, set in brick-work, with a fire-place beneath. From the inside of the flange of this vessel a similar vessel B B, of the same material is suspended, and made fast by means of the screw-pins I I. The space between the two vessels contains a metallic bath, composed of a mixture of tin and lead in equal parts. G is a cast-iron cover to the inner vessel B fitting the top edge by means of a groove, and fastened to the outer vessel A, by the screw-pins, H H. A screw F passes through a 3-armed iron-holder L L, which is made fast to a third movable iron vessel C C, placed in a sand-bath shown by N N. In the interior of this iron vessel C C, another vessel of glass or porcelain, D D, is fitted, in which the phosphorus to be operated on is placed. J is a curved pipe of iron or copper passing freely through the cover, G, but screwed into the cover, E, and having an exit at the extremity into

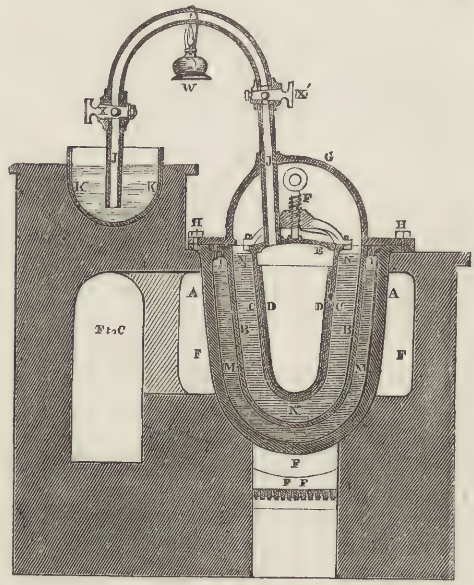


Fig. 1597.

a detached vessel K K. This contains mercury or water. If the first be employed it is well to cover it with water. This pipe J, acts as a safety-valve, the metal or water in the vessel K K, preventing the return of the atmospheric air into the inner vessel C C. W is a spirit-lamp, placed, if it is necessary, under the pipe

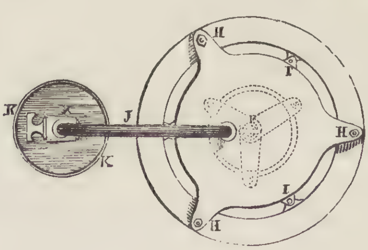


Fig. 1598.

J, for the purpose of keeping the same hot, to prevent clogging of the pipe by the condensation of distilled phosphorus. X is a stop-cock to prevent the ingress into C C of the contents of K K, or of the atmospheric air, and should be closed before the apparatus in the furnace is allowed to cool down, or the vessel K K is removed.

The cover G is not essentially necessary, but is used chiefly as a means of preventing accidents. Between the end of the screw F and the cover E, a small but strong concave disc or spring of steel should be inserted, and so adjusted as to give a slight play to the cover E, in case of violent action arising in the interior, or the stopping up of the pipe J. Neither of these accidents is likely to occur if the operation is conducted with proper attention. The whole apparatus as represented, is set in brick-work, with suit-

able furnace and flues F F for the purpose of heating it, and maintaining the temperature required for the process; the phosphorus to be converted into an amorphous state is to be previously melted and cooled under water, and dried as much as possible. The mode of operation is then as follows: The cover of the inner vessel is to be raised, the phosphorus deposited, and the covers E and G replaced. A fire is then lighted under the outer vessel A A, and the temperature raised to such a degree as shall be sufficient to drive off the air and also the gases which may be generated in the interior vessel: these will escape at the exit of the pipe J, which dips into quicksilver or water in the vessel K K. The action of water in the vessel K K, when quicksilver is employed, is useful, in order that any phosphorus which may distil over and pass down the pipe J, may be covered thereby. The temperature is to be gradually raised, until bubbles escape at the end of the pipe J, which take fire as they enter the air. When these bubbles have escaped freely for some time, the temperature may be raised, until it has attained a point of 500° Fah. In order to judge of the temperature a thermometer is placed in the metallic bath before described. The temperature must be maintained for a certain time, the length of which depends so much on accompanying circumstances, that it can only be determined by experience, at a point within a few degrees of the before-mentioned elevation, perhaps rather higher than lower. As soon as the phosphorus is converted into an amorphous state, the vessel may be allowed to cool down. The phosphorus is then taken out, to effect which it may be necessary to break the glass or porcelain vessel. It may be desirable to increase the pressure on the vessel C C and D D, and for this purpose the vessel K K should be deepened, so as to contain more mercury, and by this means a pressure of an atmosphere or even more may be gained. In this case it will be necessary to remove the disc or spring so soon as the steam and fiery bubbles which arise in the first part of the process have ceased to appear at the end of the pipe J.

The phosphorus is then to be levigated under water, from which it may be drained by being placed in a bag or on a filter. If the operation has been successfully conducted, the amorphous phosphorus produced contains only very slight traces of common phosphorus. The levigated phosphorus, while moist, should, in order to purify it, be then spread thinly for convenient working on separate shallow trays of sheet-iron or lead, and these trays can be so placed alongside each other as to receive the heat of steam, or of a heated bath of water, or of chloride of calcium, or of sand, or of each consecutively, in this order; but whichever be employed, the temperature must be raised gradually, and the phosphorus frequently stirred until the disappearance in the dark of all luminous vapour shall show that the whole of the adhering crystalline phosphorus has become oxidized.[1] The operator should have water at hand to quench any fire that might arise before the whole mass was perfectly oxidized. When the process of purification is thus far completed, the phosphorus must be washed until the water in which it is so washed shows no trace of acid when tested. In case the amorphous phosphorus produced contain too large a proportion of unconverted phosphorus, the latter may be washed out by means of bisulphuret of carbon.

In the above process the temperature must be carefully regulated, for if too high, a powerful explosion will take place in consequence of the amorphous phosphorus being suddenly reconverted into ordinary phosphorus, and that again into a highly elastic vapour. If we suppose the thawing point of ice (32°) and the boiling point of water (212°) to approach each other very nearly, a similar effect might be expected on applying heat to ice. This liability to explosion required the apparatus to be made very strong and secure, and it has happened that many days produce of amorphous phosphorus has by a sudden explosion been entirely reconverted into common phosphorus.

The amorphous phosphorus occurs in several forms according to its position in the converting vessel D D, and the subsequent purification. Those portions which are but partially pure will ignite when struck with the edge of a knife. The purer lumps will bear a high temperature, and holding to the fire without inflaming. The purest of all may be dipped into sulphuret of carbon or spirits of wine, and being ignited the spirit will all burn off without setting the phosphorus on fire.

The lumps are occasionally of a bright scarlet colour, but usually of a dark purple red; some are heavy with a metallic aspect; some light, almost like pumice-stone in the handling, and very friable. In the formation of the latter the amorphous phosphorus was probably partially formed, and the common phosphorus distilled out of it, leaving the porous mass. Some of the lumps are light enough to float on water.

The great practical value of this scientific discovery, arises from the fact that phosphorus in this state is not injurious to the persons engaged in the manufacture of lucifer matches. The dreadful disease to which these persons are liable, would be supposed to be a sufficient inducement to manufacturers at once to resort to the new and innocuous form in preference to the old and dangerous form of the element in question, provided it were capable of being applied with the same efficacious results; and it might be reasonably supposed that the public would patronise the new matches, not only on the score of humanity, but also on account of the increased safety which pertains to the amorphous phosphorus matches. But as a writer on this subject in the *Pharmaceutical Journal* (September 1852) well observes, "it is difficult to introduce any innovation of this kind into an extensive branch of manufacture. A series of experiments must be made to test the efficacy of the

(1) The manufacturers state that this process is found tedious and very difficult, and is superseded by the use of an appropriate solvent, by which all the adhering ordinary phosphorus is easily and quickly eliminated.

new preparation, the most advantageous mode of employing it, the quality of the goods and the economy of the process. In the mean time the several departments of the manufactory are progressing like clock-work. All hands are busily employed, the proprietor is fully occupied with superintending the operations and the accounts, and a large box of amorphous phosphorus remains in the office unpacked, waiting for a convenient opportunity to complete the experiments."

In order to place in a strong light the evils resulting from the use of common phosphorus, we will state a few particulars respecting the jaw disease. In the Dublin Quarterly Journal of Medical Science for August 1852, the nature of the disease is thus described by Mr. Harrison:—" An affection ensues which is so insidious in its nature, that it is at first supposed to be common tooth-ache, and a most serious disease of the jaw is produced before the patient is fully aware of his condition. The disease gradually creeps on until the sufferer becomes a miserable and loathsome object, spending the best period of his life in the wards of a public hospital. Many patients have died of the disease; many unable to open their jaws have lingered with carious and necrosed bones; others have suffered dreadful mutilations from surgical operations, considering themselves happy to escape with the loss of the greater portion of the lower jaw." [1] It is stated that the diseased bone has a spongy cellular appearance with excrescences of a similar character adhering to it; that the teeth generally continue sound and white, while the jaw which contains them is altered in texture, dead and discoloured. At Mr. Dixon's manufactory at Newton Heath near Manchester, many persons who have suffered from the disease and recovered, have returned to their work, but not to the dipping department. Doubtless the poor people had no other employment to turn to on leaving the hospital. "In the museum of the Manchester Infirmary is the lower jaw of a young woman who is now at work. Her face is much disfigured by the loss of her chin, and on looking into her mouth, the root of the tongue is seen connected with her under lip, the space formerly occupied by the jaw being obliterated by the contraction of the cheek. A young man who has lost his jaw is also in the factory. These are not isolated cases. It is stated in the factory that the work-people have sometimes applied the phosphorus paste to decayed teeth, under the idea that it was a cure for the tooth-ache, and to this imprudence some of the early cases of the disease are attributed. The frightful nature of the disorder is now sufficiently understood to serve as an incentive to greater precaution. Increased attention has been paid to ventilation and cleanliness, and the practice of taking meals on the premises is not allowed. It appears, however, from the statements of some of the work-people who are engaged in the phosphorus dipping room, that their clothes become incandescent in the dark, and although the cases of the disease are less frequent than they have been formerly, a security against its recurrence is not attained." We have been assured by a manufacturer, that the palm of the hand of a child employed in simply placing the covers on the boxes when filled with matches, will be found luminous in the dark.[2]

Various attempts have been made to remedy the evil. Camphor has been added to the composition: it conceals the smell and is said to act as a prophylactic. It has been suggested to expose oil of turpentine in saucers about the workrooms as a solvent for the fumes of phosphorus. A sponge moistened with a solution of soda or potash tied over the mouth has also been used, and it is recommended to the dippers to use a mask with a tube communicating with the external air. The quantity of phosphorus employed in the paste has been greatly diminished; but all these expedients only serve to mitigate the evil, and all of them except the last are attended with an increase of expense. Manufacturers will not use camphor or turpentine, even if they could be proved to be efficacious in getting rid of the fumes, which we much doubt; and even if the masters found the means the work-people would neglect them, and even if the larger manufacturers would take all needful precautions, there are a great many small ones, whose children work in London garrets, who will never be cared for.

To ensure the general introduction of the new phosphorus it is only required that some enterprising manufacturer should employ it in his matches, make the public understand its merits, and that he will use no other: any slight increase of cost (and we are assured it will be but slight) will be more than covered by the patronage that will be extended to him, and other makers must follow his example. There are, we know, several manufacturers who are so desirous to preserve their workpeople from the dangerous tendencies of the old phosphorus, that we believe when some further investigations shall have discovered the best and most economical adaptation of the new kind to their object, they will rejoice (even if in the first instance at some small pecuniary sacrifice) to avail themselves of its discovery, and when this point is

(1) The history, nature, treatment, &c., of the disease is very fully investigated in a German work entitled, "Die Krankheiten der Arbeiter in den Phosphorzündholzfabriken insbesondere das Leiden der Kieferknochen durch Phosphordämpfe. Vom Chemisch-physiologischen, medicinisch-chirurgischen und polizeylichen Standpunkt bearbeitet von Dr. Freiherrn Ernst von Bibra und Dr. Lor. Geist.—Erlangen, 1847."

It appears that out of 68 cases to which attention had been directed, 15 deaths had occurred, 15 had recovered (some, however, with loss of the jaw-bone), 15 remained under treatment, and the issue of the remaining 21 cases was unknown.

The disease spares neither age nor sex, nor does it require any very long exposure to produce its effects, for these have been developed in a marked form in cases where the persons employed did not touch the matches, but were engaged in adjoining rooms preparing the wood or making the boxes. It has been known to attack those engaged in overlooking the factory, and in some cases it has appeared long after the individuals had left the employment.

(2) It is stated that the authorities of Erfurt, in Prussia, require a periodical visitation of the match factories, with a view to the dismissal of all who are found to have unsound teeth.

gained, the interests of humanity would seem to require that the use of the old article should be abandoned, if not prohibited.[1]

The objections to matches made with common phosphorus are numerous: they are luminous in the dark,[2] they have an offensive smell, they are poisonous (children have been killed by sucking the matches, and we have heard of jaw disease being produced by children playing with them); fires have been produced by their spontaneous ignition; they contract damp from the air, and lose their property of igniting by age.

Matches made with the new phosphorus produce no light in the dark under 400°; they have no smell, are not liable to contract damp, and may be placed on a hot mantle-shelf without taking fire: they are thus adapted to moist and hot climates, and will keep for any length of time without change. The Editor has in his possession samples of matches, made in 1851, by different manufacturers, containing a large proportion of amorphous phosphorus; they act well, and appear to be wholly unchanged by time.

The extensive diffusion of common phosphorus in the composition with which lucifers are tipped, must have some injurious action on the health of all persons, for there is, probably, not a house in Europe or America, scarcely a room, that has not its box of lucifer or congreve matches. It is only this general demand that at all accounts for the enormous production of the match factories at home and abroad. At Messrs. Dixon & Co.'s factory, Newton Heath, from 450 to 500 persons are employed. The average daily production of the finished article varies from 6 to 9,000,000. The usual weekly average is 43,000,000, and allowing 50 weeks to the year, the annual production of this single factory is 2,160,000,000. Taking the population of the British Islands at 30,000,000, we have an allowance of 72 matches for every man, woman, and child. Such also is the cheap rate with which matches are produced, that 14,400 matches in 144 boxes can be sold wholesale for the small sum of sixteenpence, even when made and paid for at the English rates of labour.

In and previous to the year 1844, the whole of the phosphorus consumed in this country was imported from abroad. The amount of duty paid showed a consumption of about 14,000 lbs., and it is the opinion of Messrs. Sturge of Birmingham,[3] (who are large manufacturers and exporters of phosphorus, and are at present engaged in working the patent for the red phosphorus,) that the consumption has not greatly increased since that time. The constant reduction in the price of matches has naturally led to repeated diminutions in the proportion of phosphorus, the most expensive ingredient in the dipping composition; to which it is very likely the fear of the phosphorus disease has also, in recent times, contributed. Most of the English makers have continued to use chlorate of potash after it had been much disused in Germany; and the very low price at which this salt can now be purchased has favoured its increased employment to the diminution of that of phosphorus.

The number of persons engaged in the manufacture in England must be considerably over 2,000. In addition to the large manufactory near Manchester, and smaller ones in other towns, there are at least 4 considerable makers in London and its vicinity, and a very large number of small makers, the consumption of whose wares in London alone is very great.

On the continent of Europe the extent and economy of the manufacture are also most remarkable. Manufactories of phosphorus are to be found in France, Prussia, Baden, Bavaria, Austria, Sardinia, but only within the last few years in England. Manufactories of matches have spread all over Europe, from Transylvania on the borders of Turkey, and near the Black Sea, to the inland lakes of Sweden, and the Finland shore of the Gulf of Bothnia. In the United States of America and in Central America these factories are also to be found. The export manufacture of Germany is being continually extended on account of the abundance and cheapness of timber and of labour, and the preparation by the poor in winter of the turned wooden boxes for containing the matches. In order to encourage the industrial habits of the poor, the Government in Hanover, and probably in other parts, supports the manufacture by giving the wood out of its forests at a merely nominal price, a huge pile of billets being sold for a few pence. At Darmstadt, Nuremberg, in Bavaria, at Ulm and Gmund, in Wurtemberg, are very large manufactories, two of them making more than 6,000,000 matches per diem. The German manufacturers have their agents in this country, and large quantities of matches are imported into Hull and London, and being well packed in cheap but substantial cases, they are carried by the railway companies as *Toys*, while the produce of our own manufactories is as a general rule refused to be conveyed.

Assuming, as is done in the Jury Report [see MATCHES], that Austria manufactures 50,000 cwt. of matches, the quantity produced in Europe probably exceeds 200,000 cwt. per annum. It would require 100 merchant vessels of average tonnage to accommodate this quantity as cargo. It is estimated also in the Jury Report, by M. Payen, that 30,000 kilogrammes (590 cwt.) of phosphorus for matches are annually consumed in France. Professor Schrötter mentions in connexion with the Paris Exhibition of

(1) Messrs. Dixon assure us that they are anxious to adopt every available means that may be conducive to the health and comfort of their workpeople, and that if they have not yet made use of the amorphous phosphorus in the manufacture of lucifer matches, it is simply because they have not been able to make it succeed. "Whatever future results may arise from further experiments we cannot pretend to say, but trust to chemical science to remove the dreadful disease arising from the use of the present phosphorus." 7th February, 1853.

(2) We have already stated how minute a quantity of common phosphorus may be detected by its luminous property. Should the red phosphorus come into general use in the manufacture of matches, the manufacturer will not be able without detection to employ the old phosphorus for the new, since a single grain of the former mixed with 1,000 grains of glue thinned with water will shine when gently heated, and if applied to matches will become luminous by the warmth of the hand.

(3) We have to express our obligations to these gentlemen, as well as to Mr. Albright, for much valuable information in this article.

1849, that one maker produced 3,000 kilogrammes of phosphorus monthly; but a large proportion of this was for exportation. It has since much increased, and we believe that the conjoined English and French product of phosphorus would in 1853 be little short of 300,000 lbs. per annum. A German manufacturer informs Messrs. Sturge that 3 lbs. of phosphorus suffice for from 5 to 6 million matches of German make. If we divide 300,000 by 3, and multiply by 5 millions, we thus get 500,000 millions of matches as the annual product consequent on the consumption of the French and English phosphorus.

PHOTOGRAPHY is the art of drawing or producing pictures, or copies of objects, by the action of light (*φῶς, light*) upon certain chemical preparations. Of late years the action of the chemical rays of the solar spectrum has been much studied, and the varied and beautiful phenomena presented thereby have been included in a distinct branch of science, termed *Actino-chemistry*, or simply *actinism*, which means *ray-power*. This includes all those varied effects to which have been applied the terms, *Daguerreotype*, and *Talbotype* (from *Daguerre* and *Talbot*, the names of the founders of the art of producing sun pictures); and also *photography*, or drawing by *light*, and *heliography*, or drawing by the *sun; Chrysotype*, in which iron and gold are employed; *Cyanotype*, in which impressions are produced by the salts of iron, in combination with those of cyanogen; *Anthotype*, where the juices of the wild poppy, stock, rose, &c., are effaced by the action of light. We have also such terms as *Ferrotype*, *Energiatype*, *Chromatype*, *Calotype*, and many others.

The ancients seem to have been acquainted with the fact that the colours of some of the precious stones were affected by exposure to the rays of the sun. The alchemists discovered that the horn-like substance prepared by fusing chloride of silver (hence called *horn-silver*, or *luna cornea*), became black by exposure to the light. Scheele examined the action of the different rays of light upon the salts of silver; and in 1801 Ritter ascertained the existence of invisible chemical rays beyond the limits of the visible spectrum. Many other scientific men recorded some interesting facts respecting the chemical action of the solar spectrum; and in 1802, Sir Humphry Davy published in the Journal of the Royal Institution, "an account of a method of copying paintings upon glass, and of making profiles by the agency of light upon nitrate of silver." Mr. Wedgwood was associated with Davy in this inquiry. They succeeded in obtaining copies on prepared leather, or paper, of images of leaves, the wings of insects, and other small objects, as shown by the solar microscope, but they did not succeed in fixing the drawings on the paper. In 1814, M. Niepce, of Chalons, on the Soane, is said to have first directed his attention to the production of pictures by light. He pursued his studies for about ten years, without much success, when he became acquainted with M. Daguerre, who had been endeavouring, by various chemical processes, to fix the images obtained by the camera obscura. In December, 1829, they entered into partnership, by deed, for mutually investigating the subject. In 1827, Niepce sent a paper to the Royal Society on the subject of his heliographical discoveries, but as he kept his processes secret, the Society could not, by their laws, receive his paper. The paper was accompanied by specimens, which, however, do not appear to have been very successful. In January, 1839, Daguerre's discovery was announced, and the exquisite pictures produced by him were exhibited, but his process was not made known until the following July, after a bill had been passed securing to him a pension of 6,000 francs for life; and also a pension of 4,000 francs to the son of Niepce, with one half in reversion to their widows. On the 31st January, 1839, six months before the publication of Daguerre's process, Mr. Fox Talbot communicated to the Royal Society an account of his photographic discoveries, and in February published his method for preparing a sensitive paper for photographic drawings. It appears that Mr. Talbot had practised his method from the spring of 1834, and had devised it somewhat earlier.

After the publication of the two methods, the art was taken up by various scientific men, and a rich crop of discoveries speedily rewarded their labours. Sir John Herschel, writing on this subject in 1840, says:—"It is no longer an insulated and anomalous affection of certain salts of silver or gold, but one which doubtless, in a greater or less degree, pervades all nature, and connects itself intimately with the mechanism by which chemical composition and decomposition is operated. The general instability of organic combinations might lead us to expect the occurrence of numerous and remarkable cases of this affection among bodies of that class, but among metallic and other elements, inorganically arranged, instances enough have already appeared, and more are daily presenting themselves, to justify its extension to all cases in which chemical elements may be supposed to be combined with a certain degree of laxity, and, so to speak, in a *tottering equilibrium*. There can be no doubt that the process, in a great majority, if not in all cases which have been noticed among inorganic substances, is a deoxidizing one, so far as the more refrangible rays are concerned. It is obviously so in the cases of gold and silver. In that of the bichromate of potash, it is most probable that an atom of oxygen is parted with, and so of many others."

This distinguished philosopher has in the course of his inquiries enlarged the boundaries of the solar spectrum, and laid the foundation of the new science of actinism. Fig. 1599 exhibits the spectrum as it is at present known. The seven colours included between A and B, represent the spectrum as discovered by Newton. Below the ordinary visible red is another ray *a*, distinguished as the *extreme red* or *crimson* ray: this may be detected by examining the spectrum through a deep blue glass. At the upper end of the spectrum is the *lavender* ray *b*, which is seen when the spectrum is received on a sheet of yellow paper. The curves C D E represent the relative maxima of

heat, light, and *actinism.* F is a second apparent maximum of the chemical power; hence it will be seen that the chemical power is greatest in the violet ray opposite to E, and ceases at *d* and *e*, slightly increasing at F. The yellow rays destroy all actinic power, and it is here at C that the light is most

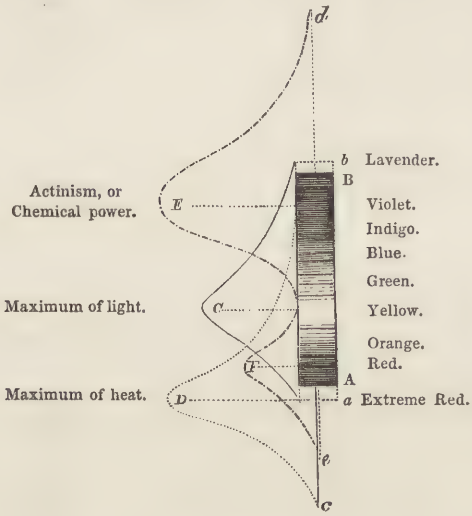


Fig. 1599.

intense; it ceases at *a* and *b*. The heat is greatest at D, and disappears at *b* and *c*. The effect of the yellow rays in diminishing the actinic power, is shown by the fact that near the equator a much longer time is required for impressing a photograph than in London or in Paris. Dr. Draper found that in proceeding from New York to the southern States, the space protected from chemical change by the yellow rays regularly increased. A similar result is found between spring and summer; photographs being more readily obtained in March and April, than in June and July. The morning sun also, between 8 and 12 o'clock, produces much better effects than can be obtained after noon.

In the preparation of photographs the chemical rays of the spectrum form the *pencil*, and certain delicate chemical preparations on the surface of paper or of metal the *drawing board*. But it is necessary that the rays should form an optical image upon the chemically prepared surface, under such circumstances that no other light shall produce any effect, except those pencils which depict the image. For this purpose a good *camera obscura*[1] is necessary. The principle of this instrument was stated in the article LIGHT [page 159 note], but it may be further illustrated here. When the sun is shining through a small hole, a round luminous spot will be seen on a screen placed for the purpose a considerable distance behind it, and this spot will increase in size as the screen is made to recede from the hole. The spot is in fact an *image*, or representation, of the face of the sun, the light from every part of the sun's disc passing through the hole, and continuing its course in a right line beyond it, till it reaches the screen; so that every point in the sun's disc has a point corresponding to it on the screen. So also, if a pinhole in a card be held between a candle and a piece of white paper in a dark room, an exact image of the flame, but inverted, will be depicted on the paper; and this image will enlarge as the paper recedes from the hole. If in a dark room a white screen be extended at a few feet from a small round hole, an exact picture of all external objects in their natural colours and forms, will be represented; moving objects being shown in motion. See Fig. 1600,

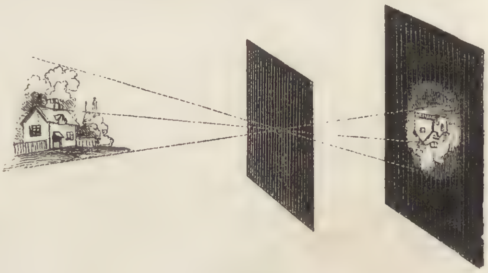


Fig. 1600.

Now as all objects exposed to light are luminous, and every physical point of their surface radiates light in all directions, so every point in the screen receives light at once from every point in the object. The same may be said of the hole; but the light that falls on it passes through and continues its course in straight lines behind. Thus the hole becomes the vertex of a conoidal solid prolonged both ways, having the object for its base at one end, and the screen at the other; and the section of the solid by the screen is the picture projected on it, which must evidently be an exact, but inverted, representation of the object.

The effect of these experiments is greatly improved by the use of a convex lens of a focal length somewhat less than the distance of the surface on which the picture is projected, the images being in such case much more vivid and distinct. Some of the objects are, however, imperfect and ill-defined, unless they happen to be situated at the same distance from the aperture, because the focus of the lens cannot be at once adjusted to near and remote objects. In the

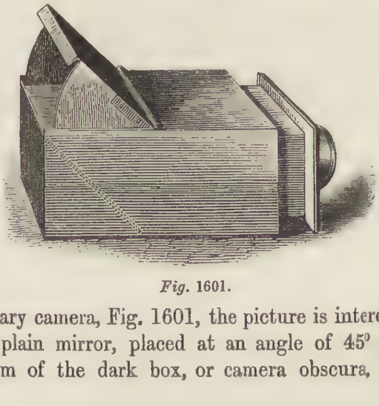


Fig. 1601.

ordinary camera, Fig. 1601, the picture is intercepted by a plain mirror, placed at an angle of 45° to the bottom of the dark box, or camera obscura, and is

(1) This instrument was first described by John Baptista Porta, in his *Magia Naturalis*, published towards the end of the fifteenth century.

thence thrown upwards to the surface of a plate of ground glass, or, what is better, a film of skimmed milk dried upon a plate of glass. For the sake of accuracy the ground on which the picture is received should be hollow, and part of a sphere whose radius is the focal distance of the convex lens.

For the practice of photography, the camera should possess "a flat field, a sharp focus at great inclinations of the visual ray, and a perfect achromaticity." The simplest form of instrument, Fig. 1602, consists of a wooden box, in the front of which slides a brass tube, containing a meniscus lens *l*, the radii of the curves of which are in the proportion of 2 to 1; there is also a diaphragm or stop a little way in front of it.

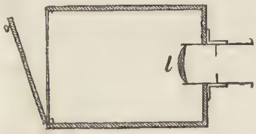


Fig. 1602.

At the back of the box is a frame, with a piece of ground glass for ascertaining the focus, and another frame so constructed that the prepared paper can be placed between a plate of glass and a smooth surface of wood or slate, and in front of the glass is a slide to shield the paper from the light until it is introduced into the camera. With such an instrument as this it must be remembered that the violet or chemical rays focalize nearer to the lens than the more luminous rays which produce a bright focal image, so that in order to produce a well-defined photographic picture, the lens must be brought towards the prepared surface, so that the violet rays may form a focus. Some cameras are furnished with a strip of wood or ivory graduated both for the optical and the chemical focus, so that the instrument can be set by measuring the distance of the object to be copied, if near; if it be at a distance it may be roughly calculated. An achromatic lens is necessary, however, to the production of finished photographs. Such a lens may be *single* or *compound;* the one being usually employed for views where a considerable time can be allowed, and the other for portraits, which require to be taken as quickly as possible. Fig. 1603 shows the compound achromatic arrangement which is screwed to the front of the camera. This tube is furnished with a movable brass cap and a series of stops or diaphragms *s*, which are employed when the lens is used for landscapes, and also for portraits, if the light is very brilliant.

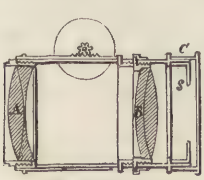


Fig. 1603.

When a long focus lens is required, as for views, the back lens A is removed, and the cap C and the stop *s* substituted: the whole of the brass mounting and the lens is reversed with respect to the camera by the screw over the lens B, by which means the lens B is placed within the camera, and can be adjusted by the same rackwork. The compound lens is always adjusted for focus by rackwork: a sliding tube suffices for the simple lens; and, as a well-constructed achromatic glass causes all the coloured rays to meet at one focus, the correct adjustment will be at that point where the object is clearly and sharply brought out on the ground glass. This is best ascertained by placing on the ground glass the wide part of a short conical tube, Fig. 1604, furnished with a magnifying-glass at its upper end. The eye can then examine any part of the image, and thus obtain the requisite sharpness of outline. A very convenient form of camera adapted for tourists is sold by the instrument-makers. It is shown, ready for use, Fig. 1605,


Fig. 1604.

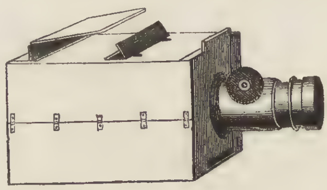


Fig. 1605.

and is thus described by Mr. Thornthwaite:[1] "The front of the camera holding the lens has a vertical adjustment, which enables the relative proportion of foreground or sky in the required picture to be altered without disturbing the position of the camera. In the body of the camera is placed two or more openings or slides, by which either the long focus lens for views, or the shorter combinations for portraits, &c., can be employed as desired. When not required for use, the lens is unscrewed, the front and slides lifted from their grooves, and the body of the camera folded together by the hinges shown in the cut; by which arrangement the camera box, together with the slides for prepared paper, glass or silver plates, frame for ground glass, achromatic lens, &c., can be conveniently packed, and in the smallest possible space, as shown in the leather case, Fig. 1606."

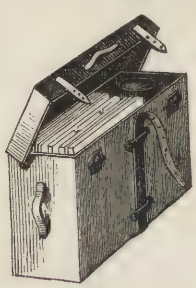


Fig. 1606.

A portable camera has been described by Mr. George Stokes. It weighs only 9 lbs. with shutter, and will take a picture 11 inches square. Its great advantage is in the shutter, which will contain from 12 to 20 pieces of prepared paper, each piece between separate pieces of blotting paper; and the whole being pressed by the front portion of the shutter, the light and air are quite excluded. When required for use (by the assistance of a very small hood) the first piece of paper is placed at the back of the glass, and the impression taken; when, by removing the millboard, it will fall back into its place; at the same time another piece can be brought forward ready for another picture, before focusing, and so on to the end. The hood is made of India-rubber cloth, and also answers the purpose of a focusing cloth, without the necessity of removing it during the day. This shutter is of

(1) "A Guide to Photography," 4th Edition, 1852. This concise treatise is intended for the use of the amateur, but chiefly to accompany the apparatus sold by Messrs. Horne, Thornthwaite, and Wood, of Newgate Street, London.

great service, saving much time and trouble in carrying several shutters.

As the camera reverses, causing objects on the right to appear on the left in the picture, a small reflecting mirror or prism may be used for again reversing the object in the camera, and thus producing a correct result.

We will now proceed to notice, very briefly, the art of photography as practised upon paper. In the first place we must remark that the selection of the paper is a point of very great importance; for unless it be of very uniform texture, it will not receive the saline solutions equally, and the result will be a spotty photograph. The best plan is to hold up the paper, a sheet at a time, between the eye and the flame of a lamp, and to select those sheets only which are free from specks and water-marks, and of equal transparency throughout. The cheaper kinds of demy contain a make-weight of sulphate of lime: and some of the varieties of enamelled satin post contain china clay, or kaolin. These should be avoided. The presence of size does not appear to be injurious, and it is recommended that old in preference to newly-made paper be used, because in old paper the organic matter of the size has passed through those changes to which it is liable, and it may be regarded as tolerably permanent, both in composition and colour. The French manufacture a paper expressly for the purpose; but Professor Hunt[1] states that it is better adapted to French than to English photographic processes. Mr. Thornthwaite recommends the blue wove post manufactured by Whatman, the paper to be cut into sheets about 9 inches by 8. In cases where highly sensitive paper is to be prepared, it is desirable to separate metallic and earthy matters by steeping the paper for some hours in water acidulated by nitric acid, and then removing all traces of the acid by leaving the paper for half an hour under gently flowing water.

One of the simplest methods of illustrating the art is by means of paper prepared with muriate of baryta, 10 grains dissolved in 1 ounce of distilled water; and the solution of ammoniacal nitrate of silver, containing about 50 grains of nitrate of silver per ounce.[2] These solutions may be applied to the paper by one of three methods:—1. A small quantity of the solution is poured upon the surface of a flat glass plate or earthen dish, and the paper is to be placed carefully on the surface in such a way as to prevent the formation of air bubbles between the paper and the solution. The back must not be wetted, and it is desirable, in the selection of the paper, to attach a small mark with a pencil to that surface which is to be prepared, so that it may be afterwards distinguished from the back or unprepared surface. The paper must be pressed gently down to the solution with a glass rod, to prevent it from curling upwards; but when the sheet has lost its rigidity, lies flat, and becomes slightly opaque, it has absorbed enough of the fluid, and may be lifted off, allowed to drain for a few seconds, and then hung up to a cross rail of wood by a couple of pins. The fluid which accumulates at the bottom edge of the suspended paper should be removed by touching it with a piece of thick filtering paper. 2. The paper is to be placed, with its marked side upwards, upon a wooden board a little smaller than the paper; a glass rod is next to be placed across the paper near the left end; a measured portion of the solution is then to be poured on the paper in front of the rod, which is to be moved backwards and forwards until the paper is properly wetted. The sheet may then be hung up to dry. 3. The paper is to be attached at the four corners by pins to a surface of blotting-paper, and the solution applied by means of a soft brush, the extreme edge being avoided; but should any of the solution flow over the edge, it will be absorbed by the blotting-paper, and thus the back of the paper will be preserved from stains. When properly moistened, the paper may be removed and hung up to dry. An ordinary brush is rapidly corroded by solutions of silver, so that it is better to use a piece of cotton wool attached to a glass tube instead. It will soon be discovered by the behaviour of the paper which of these three methods is to be preferred. If by the first method the paper take up the solution unequally, the defect may often be remedied by the friction used in the other two methods.

Any number of sheets of paper may thus be prepared on the marked surfaces, with the solution of muriate of baryta, and when dry they may be kept for any length of time without injury. When required for use, a sheet of this prepared paper is to be washed over (of course on the marked side) with the solution of ammoniacal nitrate of silver, and hung up in a dark cupboard to dry: it may then be preserved in a portfolio, or between the leaves of a book, for use; it should not, however, be kept longer than about 24 hours before being used.

The surface thus prepared soon becomes black by exposure to light, and it is obvious that if the object to be copied be previously placed upon the prepared surface, the light will act upon the uncovered portions of the surface, tracing with minute accuracy the outline of the object, and even acting through its substance, if it be partially transparent or translucent, varying the intensity of its tints with the varying translucency of the object, making them deep where but little light is capable of passing through, deeper where more light passes, and deepest of all on the exposed portions. Flat objects, such as plants, leaves, flowers, ferns, mosses, feathers, wings of insects, pieces of lace, prints, drawings, &c., are well adapted

(1) The reader interested in the study will find a *resumé* of most of the processes given in Professor Hunt's "Photography; a treatise on the chemical changes produced by solar radiation, and the production of pictures from nature by the Daguerreotype, Calotype, and other photographic processes." 8vo. London, 1851.

(2) Mr. Alfred Smee's instructions for preparing this compound are as follows:—For a two-ounce stoppled phial, place 50 grains of crystallized nitrate of silver, and pour over it 1 ounce of distilled water. When the crystals are dissolved, some strong solution of ammonia is added, a few drops at a time, and the phial well shaken after each addition. The whole becomes, first, of a dark brown colour, from the formation of a precipitate of oxide of silver; but as soon as the proper quantity of ammonia is added, the oxide of silver is dissolved, and the solution becomes perfectly clear, and is ready for use.

to this method; but in order to obtain correct and sharp outlines, the object must be pressed down upon the paper; for which purpose a frame and glass may be used. A convenient size for the glass is rather larger than a single leaf of 4to. post writing paper. The glass should be thick enough to resist pressure, and as clear as possible. The frame is represented in Fig. 1607, in front, taking a copy of a flower. Fig. 1608 shows the back, which has a plate of tinned iron or wood pressing on a cushion, and secured by a bar, the ends of which being moved into the grooves in the sides, give the required pressure to the paper, and bring it well into contact with the object to be

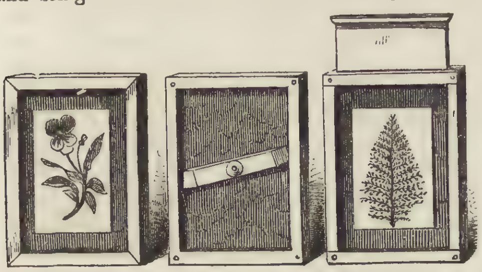


Fig. 1607. *Fig.* 1608. *Fig.* 1609.

copied. In copying leaves of plants the upper and smooth surface should be in contact with the prepared paper: thick roots or buds to a plant may be thinned down with a penknife. Fig. 1609 shows another form of frame used for the purpose. The object being thus prepared, and mounted in a shady room, or by artificial light, may now be exposed to sunshine for some minutes, depending upon the nature of the object and the sensitiveness of the paper. If the delineation be satisfactory, the next process is to fix it on the paper, by removing from it that portion of the salt of silver which still remains undecomposed. This is done by means of a solution of hyposulphite of soda, (1 oz. to a pint of water,) contained in a flat dish large enough to contain the drawing. But before this solution is used, the drawing should be placed for a few minutes in cold water, and agitated to prevent any deposit from forming on the surface: it must then be placed, face upwards, in a flat dish, and some hot water be poured over it gently, to remove the size from the paper, an effect which is indicated by the paper becoming very absorbent, and on inclining the dish, the water not running down in separate streams. The drawing may now be dried by pressing a few folds of white blotting-paper upon its surface. It may next be laid upon the solution of hyposulphite, face upwards, until the whole surface appears to be well wetted by the upward absorption of the solution; it is then to be washed in separate portions of water until the water ceases to have the sweet taste of hyposulphite of silver. When dried, the drawing may be exposed to light without being injured. In this fixing process, the chloride of silver of the prepared surface is very soluble in hyposulphite of soda, while the subchloride of silver, to which the action of the light reduces the chloride, is not: hence, when the photogenic drawing is placed in the hyposulphite, the undecomposed chloride of silver is converted into hyposulphite of silver, which, being very soluble in water, is removed in the washing.

In a drawing thus obtained, the lights and shades are, of course, reversed, with respect to the original; that is, the light parts of the original produce dark parts on the paper, and *vice versâ.* Such impressions are termed *negative*, to distinguish them from those in which the lights and shades are as they occur in nature, and which are called *positive* photographs. Positive impressions can be obtained from negative, by using the latter in the frame instead of the object itself.

We next proceed to give a brief outline of one of the methods of producing a higher order of photographs, viz. the Calotype. This process, or as it is also called, the *Talbotype,* from the name of the inventor, who has patented it, produces an image on paper which is invisible when taken from the camera; but by washing it over with a liquid containing gallic acid the picture is gradually developed. In this respect the calotype resembles the daguerreotype. The following is an outline of Mr. Talbot's process, as improved by Mr. Cundell:—

To produce a calotype picture there are five distinct processes, all of which, except the third, must be performed by the light of a lamp or candle, surrounded by a yellow glass, or in a room where the light is admitted entirely through yellow glass, or several thicknesses of yellow calico. These processes are by no means difficult; they require only care and attention.

The paper must be compact and uniform in texture, smooth and transparent, and of not less than medium thickness. A fine post paper is manufactured for the purpose, by "R. Turner, Chafford Mill." A half-sheet having been selected, its surface is to be coated uniformly with iodide of silver. This is done either by the mutual decomposition in the substance of the paper, of nitrate of silver and iodide of potassium, or else by making use of the double iodide of silver. In the one case, the paper is first prepared on one side with a solution of nitrate of silver, made by dissolving 20 grains in an ounce of distilled water, and allowing it to dry in the dark. It is next brought into contact with a solution of iodide of potassium, in which case the iodine goes to the silver, and the nitric acid to the potash. This is best accomplished by pouring the solution of iodide of potassium (1 ounce of the salt to a pint of water) in a flat dish, to the depth of about ½ inch. The prepared side of the paper, previously marked, is then placed in contact with the surface of the solution, and holding the paper by an upturned margin, it is to be gently drawn along the surface, until the lower face is thoroughly wet. This part of the operation ought not to occupy more than a minute, as the compound formed on the paper is easily redissolved. After draining for a short time, the paper is placed on a clean surface, with the wet side uppermost, until about half dry. If properly conducted, the paper is completely coated with iodide of silver, which must be retained uninjured. The

paper is also saturated with nitrate of potash and iodide of potassium, which must be completely removed. For this purpose the paper must be taken by its upturned margin, and floated on the surface of a dish of clean water, where it is to be left for 5 or 10 minutes, drawing it gently now and then along the surface; the salts, being soluble, will separate completely, and the solution thus formed will subside. If the paper be taken up, and if a drop from its surface allowed to fall into a solution of nitrate of silver produce no precipitate, the washing is complete; if a precipitate be produced, the paper must be left on the water some time longer. It should be dried, hanging up in the air by pinning one of the corners to a string. While wet its surface must not be touched. When dry it may be smoothed by pressure. This *iodized* paper is now ready for use; but it may be kept for a long time.

The second method of preparing iodized paper is the simpler of the two. About 20 grains of nitrate of silver are to be dissolved in about 1 ounce of distilled water, to which must be added 20 grains of iodide of potassium in 1 oz. of water. A precipitate of yellow iodide of silver is formed and is left to subside, when the clear liquid is decanted off, and the precipitate washed two or three times with warm distilled water, settling and draining between the washings. The iodide of silver thus freed from nitrate of potash and other impurity, has next poured over it enough water to make 1 fluid ounce, the whole being stirred up with a glass rod. Crystals of iodide of potassium are next added, one crystal at a time, each to be dissolved before another is put in. The solution gradually becomes clear and then bright, forming the double iodide of silver. This is best applied to the paper by means of the glass rod, as already noticed, and when dry, or nearly so, the paper is put into water which must be changed five or six times in about half an hour, or until the surface of the paper is of a lemon yellow colour, and a drop of the liquid from its surface does not produce a precipitate in a solution of nitrate of silver. It may then be hung up to dry, and when dry, be smoothed by pressure. In this process the iodide of silver, being soluble in a strong solution of iodide of potassium, forms the double iodide, which being decomposed on the addition of water, forms a precipitate of iodide of silver in the substance of the paper, while the iodide of potassium is dissolved out by the water. The iodized paper, if properly prepared by either of the above processes, is not sensitive to light.

The next process is that of *exciting*, or preparing, the paper for the camera. For this purpose two solutions are required, viz. a saturated solution of crystallized gallic acid in cold distilled water, and a solution of nitrate of silver, 50 grains to the ounce of water, to which is added 1½ drachm of glacial acetic acid. For the solution of gallic acid, 4 or 5 grains of the crystals are dissolved in a phial with 1 oz. of water. The phial is to be shaken, and the contents passed through a filter; the clear liquid will be a saturated solution, and it will not become mouldy so soon if the bottle containing it be placed for a few minutes in boiling water. In applying these solutions to the iodized paper, 3 drops of each are to be added to 2 drachms of water; and the gallo-nitrate of silver thus formed is to be spread over a clean surface of plate-glass. The iodized paper is to be brought down upon the liquid on the glass, and when properly wetted, which is known by its ceasing to curl up, it must be removed, and the excess of gallo-nitrate absorbed by placing over it a sheet of white blotting-paper. After this it may be placed, while damp, between the plate glasses of the camera frame ready for use. If well prepared, it may be kept for 24 hours without losing its whiteness or sensibility.

If the paper be required to be more sensitive, as for portraits, the gallo-nitrate must be diluted with less water—a few drops may suffice; but in such case the operation must be quickly and skilfully performed, as the gallo-nitrate decomposes in a very few minutes. The amount of dilution must depend upon the brightness of the day, the brilliancy of the object, and the judgment and experience of the operator. Indeed, much of the success of this art depends upon the two last-named qualities.

The paper thus prepared is now ready for receiving the object: the time of exposure may vary from a few seconds to eight or ten minutes. When the paper is removed from the camera-slide, little or no trace of the picture is to be seen; but it may be brought out by the solutions of gallic acid and aceto-nitrate of silver, mixed in equal proportions, such as half a drachm of each with half a drachm of distilled water. This mixture must be applied to the surface of the paper by any one of the methods already noticed, the whole surface being thoroughly wetted. Then, on placing it face upwards upon a plate of glass, the picture will gradually develop itself. During this operation, the surface must be kept wet with the mixture of gallic-acid and aceto-nitrate of silver, or the light parts of the picture will sink and become opaque. A gentle application of heat, by holding the paper over the steam of hot water contained in a deepish dish, will sometimes assist the bringing out of the picture. Should the picture begin to stain, and form dark waves, the excess of gallo-nitrate must be removed by placing the picture on blotting-paper on a glass plate, and moving a glass rod quickly from one end of the picture to the other. Some of the solution of gallic-acid alone is to be next poured over the picture, to complete the development.

The next operation is *fixing* the picture, or photograph, thus developed. The excess of nitrate of silver and of yellow iodide must first be removed; for which purpose the photograph is to be placed face downwards in water, and gently moved about; but the water must be changed 3 or 4 times in 8 or 10 minutes. The photograph is then to be pressed between folds of white blotting-paper. The remaining nitrate and iodide of silver may be dissolved out by placing the photograph in a warm and strong solution of hyposulphite of soda (4 oz. to the pint of water); and when the yellow colour of the iodide has disap-

peared, it must be washed in a considerable quantity of water; and, to insure the getting rid of the last portions of hyposulphite of silver, the photograph may be left for a few hours in water, and then dried between blotting-paper. The fixing is now complete; but the photograph produced by this long series of operations is *negative*, and in order to obtain impressions from it, in which the lights and shades are as in nature, another process is required, viz. *printing*.

To prepare for printing, the negative photograph is to be laid on a glass plate, and burnished with a steel or agate burnisher until the surface is equally polished and smooth. This gets rid of the woolly appearance caused by numerous projecting fibres raised during the repeated washings: the paper becomes more pervious to light, and allows of closer contact with the prepared paper which is to receive the positive impression. The light parts of the negative may also be made more transparent by scraping a little white wax over them, placing thereon a sheet or two of blotting-paper, and then passing a hot iron a few times over the latter. The sheet of paper for receiving the positive impression is prepared with muriate of baryta and nitrate of silver, as already described: the paper should be quite flat and smooth, and the negative photograph laid upon it face downwards; a morsel of wafer is then to be placed between them at one of the corners: they are then put into the reversing frame, and exposed to light. The fixing is to be performed as already described. The finished photograph is best preserved by a thin coating of gelatine, or it may be mounted in a glazed frame.

Sir John Herschel has lately communicated to the *Athenæum* a method of taking photographic landscapes on paper, as practised by his brother-in-law, Mr. John Stewart, resident at Pau. This gentleman is stated to have been singularly successful in his application of the art to the depiction of natural scenery, such as the superb combinations of rock, mountain, forest, and water, which abound in the picturesque region of the Pyrenees. These photographs are exquisite in their finish, and artistic in their general effect. "The extreme simplicity of the process employed by him for the preparation of the paper, its uniformity, and the certainty attained in the production of its results, seem to render it well worthy of being generally known to travellers. It need hardly be mentioned that the 'air-pump' employed may be one of so simple a construction as to add very little to either the weight, bulk, or expense of the apparatus required for the practice of this art. The obtaining of a *very perfect* vacuum, for the imbibition of the paper, being a matter of little moment,—a single barrel (worked by a cross handle by direct pull and push), furnished with a flexible connecting-pipe, and constructed so as to be capable of being clamped on the edge of a table, would satisfy every condition."

The following observations are confined to negative paper processes, divisible into two—the *wet* and the *dry*. The solutions employed for both these processes are identical, and are as follows:—

Solution of iodide of potassium, of the strength of 5 parts of iodide to 100 of pure water.

Solution of aceto-nitrate of silver, in the following proportions: 15 parts of nitrate of silver; 20 of glacial acetic acid; 150 of distilled water.

Solution of gallic acid, for developing;—a saturated solution.

Solution of hyposulphite of soda; of the strength of one part hyposulphite of soda to from 6 to 8 parts water.

The solutions employed are thus reduced to their simplest possible expression.

For both the wet and the dry processes the paper is iodized as follows:—In a tray containing the above solution, plunge, one by one, as many sheets of paper (twenty, thirty, fifty, &c.) as are likely to be required for some time. This is done in two or three minutes. Then roll up loosely the whole bundle of sheets, while in the bath; and picking up the roll by the ends, drop it into a cylindrical glass vessel with a foot to it, and pour the solution therein, enough to cover the roll completely (in case it should float up above the surface of the solution, a little piece of glass may be pushed down to rest across the roll of paper and prevent its rising). The vessel with the roll of paper is placed under the receiver of an air-pump and the air exhausted; this is accomplished in a very few minutes, and the paper may then be left five or six minutes in the vacuum. Should the glass be too high (the paper being in large sheets) to be inserted under a pneumatic pump receiver, a stiff lid lined with India-rubber, with a valve in the centre communicating by a tube with a common direct-action air-pump, may be employed with equal success. After the paper is thus soaked *in vacuo* it is removed, and the roll dropped back into the tray with the solution, and then sheet by sheet picked off and hung up to dry, when, as with all other iodized paper, it will keep for an indefinite time. By the action of the air-pump the paper is thoroughly iodized, and with an *equality* throughout that no amount of ordinary soaking procures. The operation is accomplished in a quarter of an hour, which otherwise generally employs one, two, or more hours. Another advantage is, that this paper is never solarized even in the brightest sun; and it will bear whatever amount of exposure is necessary for the deepest and most impenetrable shadows in the view, without injury to the bright lights.

Wet Process.—Having prepared the above solution of aceto-nitrate of silver, float a sheet of the iodized paper upon the surface of this sensitive bath, leaving it there for about ten minutes. During this interval, having placed the glass or slate of your slider quite level, dip a sheet of *thick* clean white printing (unsized) paper in water, and lay it on the glass or slate as a wet lining to receive the sensitive sheet. An expert manipulator may then, removing the sensitive sheet from the bath, extend it (sensitive side uppermost) on this wet paper lining, without allowing any air globules to intervene. But it is difficult; and a very simple and most effectual mode of

avoiding air globules, particularly in handling very large sheets, is as follows. Pour a thin layer of water (just sufficient not to flow over the sides) upon the lining paper, after having extended it on the glass or slate, and then lay down the sensitive paper gently and by degrees, and floating, as it were, on this layer of water; and when extended, taking the glass and papers between the finger and thumb, by an upper corner, to prevent their slipping, tilt it gently to allow the interposed water to flow off by the bottom, which will leave the two sheets of paper adhering perfectly and closely, without the slightest chance of air-bubbles;—it may then be left for a minute or two, standing upright in the same position, to allow every drop of water to escape; so that when laid flat again, or placed in the slider, none may return back and stain the paper. Of course, the sensitive side of the sheet is thus left exposed to the uninterrupted action of the lens, no protecting plate of glass being interposed,—and even in the dry and warm climate of Pau, the humidity and the attendant sensitiveness are fully preserved for a couple of hours.

To develop views thus taken, the ordinary saturated solution of gallic acid is employed, never requiring the addition of nitrate of silver; thus preserving the perfect purity and varied modulation of the tints. The fixing is accomplished as usual with hyposulphite of soda, and the negative finally waxed.

Dry Process.—In preparing sheets for use, when *dry*, for travelling, &c., paper *previously waxed* is not used, and thus a troublesome operation is got rid of. Taking a sheet of iodized paper, in place of floating it (as for the wet process) on the sensitive bath, it is plunged fairly into the bath, where it is left to soak for five or six minutes; then removing it, wash it for about twenty minutes in a bath, or even two, of distilled water, to remove the excess of nitrate of silver, and then hang it up to dry, instead of drying it with blotting paper. Paper thus prepared possesses a greater degree of sensitiveness than waxed paper, and preserves its sensitiveness, not so long as waxed paper, but sufficiently long for all practical purposes—say thirty hours, and even more. The English manufactured paper is far superior for this purpose to the French. To develop these views, a few drops of the solution of nitrate of silver are required in the gallic-acid bath. They are then finally fixed and waxed as usual.

These processes appear to be reduced to nearly as great a degree of simplicity as possible: stains or spots do not occur, and there is a regularity and certainty in the results that are very satisfactory. The aërial perspective and gradation of tints are admirably preserved; and the deepest shadows are penetrated and developed—speaking, in fact, as they do to the eye itself in nature. In exposing for landscape, all consideration of the bright lights is neglected, the time being limited with reference entirely to the dark and feebly-lighted parts of the view: with a $3\frac{1}{4}$-inch lens, the time of exposure has thus varied from ten minutes to an hour and a half, and the action appears never to have ceased.

The influence of the air-pump in this respect appears to be very sensible, and deserving of further examination and extension. Mr. Stewart purposes, not only to iodize, but to render the paper sensitive, with the action of the air-pump, by perhaps suspending the sheet, after immersion in the nitrate bath, under the receiver of the air-pump for a few minutes, before exposure in the camera, or by some other manœuvre having the same object in view. He has chiefly employed Canson's French paper in iodizing with the aid of the pump. Few of the English manufactured papers are sufficiently tenacious in their sizing to resist the action of the pump, but they may easily be made so; and were, in short, the English paper so far superior in quality to the French, only better sized, that is, with glue less easily soluble, even though more *impure*, there is scarcely any limit to the beauty of the views that might be produced.

A very decided advance in the art of photography has been made by the use of COLLODION (gun cotton dissolved in ether—see GUN COTTON) in a film upon glass as the surface for receiving the picture. The following instructions by Mr. Philip H. De La Motte are for a negative.[1]

Thin plate glass is used of the size of the frame, and this must be *cleaned* by washing it in water containing a small quantity of *nitric acid*, or water containing a small quantity of ammonia and tripoli mixed. The glass must then be well washed or rinsed in clean water, wiped dry, and polished with a clean leather.

To coat the Plate with Collodion.—Hold the glass by one corner, or, if large, place it in a frame,[2] and pour on the collodion, which will readily diffuse itself all over. Immediately pour the liquid off again into the bottle from one corner, and by bringing the hand which holds the glass plate down a little, the liquid will run to the edge; and, by drawing the mouth of the bottle along the edge of the plate, the collodion will run into an even surface. Very little practice will soon enable the operator to obtain a most perfect coating.

The plate is now ready for the bath. Take nitrate of silver 33 grains to the ounce of distilled water, and filter it. The dipper must be raised out of the bath, and the plate gently lodged upon the edge at the end. The plate must then be immersed in the bath, letting it remain there for half a minute. By raising it out gently it will be seen that the surface will have a greasy appearance, and the time for removing it out of the bath to the slide for the camera, will be known as soon as the greasy appearance disappears from the plate. It is well to raise the plate two or three times from the bath, that the ether may evaporate. The plate should in this wet state be placed in the slide, and put into the camera.

The time of exposure must entirely depend upon the light upon the object about to be taken, and the

(1) We may also refer to a pamphlet entitled "Directions for obtaining both Positive and Negative Pictures upon Glass by means of the Collodion Process, &c., by T. H. Hennah." This work also contains Gustave le Gray's method of obtaining black and violet colours in the positive proofs by the use of chloride of gold.

(2) The frames are manufactured by Messrs. Horne & Co

size of the diaphragm used, with the lens: for views or portraits, from one to ten seconds, and in dull weather from one minute to a minute and a half.

After exposing the plate in the camera, it must be taken from the slide and placed, collodion side upwards, upon a levelling stand.

To develop the Picture.—Pyrogallic acid 3 grains, glacial acetic acid 1 drachm, distilled water 1 ounce. Take a sufficient quantity of the above solution, pour it quickly over the plate, frequently moving the solution by blowing gently upon the plate. A few drops of the nitrate of silver solution from the bath, added to the developing solution, just before applying it to the plate, in dull or cold weather, will greatly assist the bringing out of the picture. A little practice will soon show how long each subject will require; after this pour on the plate a gentle stream of water; then add a saturated solution of hyposulphite of soda, which will, in a few seconds, dissolve the undecomposed iodide, and fix the picture; then allow a stream of water to flow all over the plate, so as to entirely get rid of the hyposulphite of soda; the picture is then finished. By applying a gentle heat to the plate, it will soon dry, when it will be fit for varnishing; the picture is then ready for printing from in the ordinary way.

Albumen has also been used both on glass and paper with very considerable success. The following instructions for albuminising glass are by Messrs. Ross and Thomson of Edinburgh:—

The white of eggs, having 12 drops of saturated iodide of potassium added to each egg, is beaten up into a large mass of froth, and allowed to stand for 10 or 12 hours, till it falls into a liquid; the albumen is then poured plentifully over the surface, which must be very clean; and when all is covered, the glass is turned gently over, and made to revolve at a moderate rate before a clear fire (being suspended by worsted thread and a bent brass wire, which catches the opposite corners of the glass), until it begins to crack at the edges; these cracks will soon spread over the whole; it will keep any time in this state, or it may be used as soon as cool. Before being put in the camera it is dipped into nitrate of silver, 70 grains to the ounce of water, having a twentieth part of strong acetic acid mixed with it; immediately after being dipped in this it is washed in water once or twice; the picture can be taken on it now, or 6 or 8 hours after; 3 or 4 minutes will suffice for light objects; red or green will of course take longer. It is developed by pouring a saturated solution of gallic acid upon the prepared side, and spreading it with a piece of cotton wool; the picture then appears slowly, of a reddish colour. When brought up as far as it will come, a little of the silver solution is mixed with gallic acid, and spread over it with a piece of clean cotton; the picture then assumes a darker and more vivid appearance, when it is fixed by means of hyposulphite of soda, and this, when washed off, finishes the negative.

We now proceed to notice the practice of the art upon metal.

Daguerreotype pictures are taken on the surface of plated copper plates, which are now manufactured at Sheffield for the purpose, and when cut to the required size, are planished with the hammer, and polished at the lathe. In order to produce a permanent picture on one of these plates, six distinct operations are required.

1. *Cleaning the silvered plate*, so as to obtain a perfectly pure and polished surface.—The materials required are, calcined *tripoli* in an inpalpable powder, kept in a box with a piece of fine muslin tied over it; *lampblack*, calcined in a crucible till it ceases to smoke, then reduced to fine powder in a glass or porcelain mortar, and kept for use like the tripoli; *rouge*, the finest washed, preserved in the same manner; and, lastly, *olive oil.* The cleaning is best performed at a lathe, with circular buffs covered with unbleached cotton velvet. The buff No. 1 is prepared with olive oil and tripoli; No. 2 with tripoli alone; and No. 3 with lampblack and a little rouge, or with lampblack alone. The plate is mounted in a holder, and pressed against the buff No. 1, which quickly removes any former picture, scratches, or tarnish. The plate is then lightly wiped with cotton wool, to remove the superfluous oil, &c.; and the No. 2 buff is used until all the oil is got rid of, and the plate appears to be equally polished. The plate is next placed, with the silver side upwards, on a stand, Fig. 1610, and the flame of a spirit-lamp applied to the under surface, until a slight smoke rises from the plate and it assumes a whitish tint: this gets rid of every trace of oil, and the plate then receives its final polish from the buff No. 3.

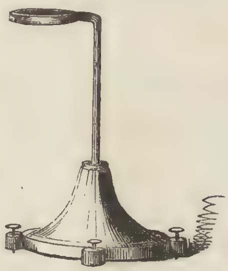


Fig. 1610.

Should a lathe not be procurable, the polishing by hand is performed by a number of cotton-velvet buffs, varying in size with that of the plates. The first buff is prepared with tripoli and oil, the second and third with tripoli alone, and the fourth with prepared lampblack and a very little rouge. The plate is put face downwards upon the buff No. 1, and then, by means of a plate-holder, Fig. 1611, made adhesive with prepared India-rubber, the plate is moved briskly over the surface of the buff, with a slight pressure, for a minute or two; it is then cleared from oil, &c., with cotton wool, and rubbed lightly on the buff No. 2; then on No. 3 with fresh dry tripoli; next heated with a spirit-lamp, and finished on the buff No. 4. The buffs should be kept in separate wooden cases, and be quite dry at the time of using. The plates, after being polished, should be kept free from contact, in a vertical position, in a box, Fig. 1612, furnished with grooves; and when a plate is about to be used, it should receive a final polish, and

Fig. 1611.

have its grain laid in a particular direction by means of a buff, Fig. 1613, covered with cotton velvet or soft doe-skin. The plate should be briskly rubbed for a few seconds, until all the fine lines on its surface appear in one uniform direction. For portraits, these lines should be across the direction of the face, and for landscapes, in the direction of the view.

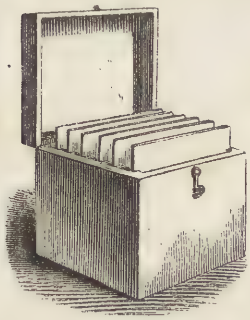


Fig. 1612.

Fig. 1613.

Some persons prefer to deposit on the silver surface a coating of pure silver, by means of voltaic electricity [see ELECTRO-METALLURGY], which is polished and prepared for the second operation, now to be described.

2. *Applying the sensitive coating.*—The sensitive coating is prepared by means of vapour of iodine and an accelerating material, such as chloride of bromine. The latter is prepared by mixing 1 oz. of a saturated solution of bromine with 1 drachm of strong hydrochloric acid.[1] The *bromine apparatus*, used for holding the plate during the application of the coating, is represented in Fig. 1614. It consists of two deep glass pans, contained in a wooden box, at the back of which are two openings, covered with white paper, one opening for each pan. In front of the box, opposite the back openings, are two other openings with flaps opening outwards, and each flap is lined with looking-glass. The apparatus has also two glass covers, and a series of wooden frames sliding over them. In one of the pans is put half an ounce or an ounce of pure iodine in crystals, and in the other pan water to the depth of about half an inch, with a quantity of the chloride of bromine sufficient to bring the solution to the colour of pale sherry. The pans are then closed with their covers, and the apparatus placed before a window in a moderate light. The silver plate is next placed in its frame at the top of the apparatus over the iodine, and the glass cover removed, so as to expose the plate to the action of the vapour. The small mirror is then adjusted to such an angle that, by looking into it, the white paper at the back is seen reflected from the surface of the silver plate, and thus any change of colour may be instantly detected. When the surface is of a light straw-colour, the cover is put over the iodine, and the slide holding the silver plate shifted over the pan containing the chloride of bromine, the cover of which is withdrawn, the mirror adjusted, and the glass cover removed so as to expose the plate to the vapour. When it has attained a deep yellow colour, it is again brought over the iodine; and when it has acquired a rose tint, it is to be placed in the camera frame. Should the plate be left too long over the iodine in the first coating, and the rose tint begin to appear, it must be brought to a full rose over the accelerator, and then to a blue over the iodine. If this fail to produce a good result, the plate must be repolished.

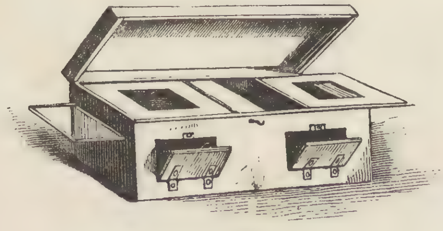


Fig. 1614.

(1) There are many other preparations of bromine, known as *eau bromée*, *bromide of iodine*, *Hungarian solution*, *Woolcott's American accelerator*, *bromide of lime*, &c.

3. *Exposure in the camera.*—The camera being mounted on a firm support, the focus is carefully adjusted until a perfectly distinct image of the object is seen on the ground-glass plate, which occupies exactly the position in which the silver plate is to be placed; the light is then shut off by a brass cap, the plate introduced, the cap removed, and the plate exposed to the light. The time required for making the impression may vary from 1 to 60 seconds, depending to a great degree upon the season of the year, the time of the day, and the brightness or clearness of the atmosphere. When, according to the judgment of the operator, sufficient time has been allowed, the light is shut off, and the camera removed to a dark room, in order to bring out the picture, at present invisible, by exposure to the fumes of mercury.

4. *Mercurializing the plate.*—The mercury box, Fig. 1615, is of wood, with an iron cup in the bottom for holding the mercury, which is heated by a spirit-lamp. The upper part of the box is furnished with grooves for receiving the same sliding frame as was used for the plate in the camera. In front of the box is a small window of yellow glass, furnished with a sliding shutter. From 4 to 6 oz. of pure mercury are put into the cup, and this is heated until the outside of the cup begins to be too hot to be conveniently touched; the plate may then be put in its place in the mercury box, and the development of the image can be watched by holding a piece of lighted paper at the side, or by looking through the yellow glass in front. If the operation be conducted slowly, a clearer and sharper outline will be produced than if done quickly; the time, however, may vary from 5 to 20 minutes. The box should be kept at a temperature of about 90°. The mercury must be kept pure and clean, and be returned to its bottle after the operation.

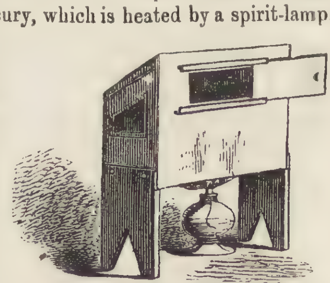


Fig. 1615.

5. *Removing the sensitive coating.*—When the picture has been distinctly brought out, the plate is removed from the mercury box and dipped quickly into a solution of hyposulphite of soda (2 oz. to the pint). The colour will gradually disappear: the plate is then to be put into a vessel of filtered water, to remove the excess of hyposulphite, after which a little pure water is to be poured over the surface of the plate.

6. *Fixing the picture* is performed with a solution of gold, prepared by dissolving 15 grains of chloride of gold in a pint of water, and gradually adding it to a mixture of 60 grains hyposulphite of soda and 8 oz. of water, the whole being well stirred after each addition. The solution will be at first slightly yellow, but will become perfectly limpid. The solution is to be poured over the plate, so as to cover it entirely, and the flame of a large spirit-lamp applied to the back, moving the plate about over the flame: the picture will brighten, and in a minute or two come out bold and distinct. This effect being produced, the liquid is to be thrown off, and the plate dipped into water, washed and dried. A large plate may be dried by placing it on a smooth piece of copper, and pouring some boiling distilled water over its surface, inclining the plate so that the water may run off from one of the corners, and it will very soon become quite dry: or the plate may be dried by placing it on the fixing stand, made horizontal by levelling screws, and applying the flame of a spirit-lamp below it. Or the plate may be held by pliers at one corner, some filtered distilled water poured over it; then inclining the plate, the water will flow to the side, and may be removed by touching it with blotting paper; the spirit-lamp is then to be applied to the upper corner, and the flame gradually brought down. The formation of spots may be to a great extent prevented by blowing gently downwards on the plate. Care must be taken not to overheat the plate, or some of the silver will become detached. The lamp must be instantly removed when small bubbles of air form on the surface of the metal.

Some attempts have been made to improve daguerreotypes by the application of colour. The colours are dry, ground extremely fine with dry gum or starch, and dusted on with a fine camel's-hair pencil, a very small quantity of colour being taken up at one time, and blowing off the superfluous colour with an elastic bottle of caoutchouc; when the proper tint is produced, it is fixed by breathing on the plate. Or the colour mixed with spirit of wine may be applied with a hair pencil, and dry colour applied over it. Carmine, chrome-yellow, ultramarine, and their combinations, are best adapted to this purpose. In the application of colour to a daguerreotype, or "in visibly uniting art and science on the same plate, the operator should be possessed of knowledge and feeling sufficient to know the proportions in which art and science should intermingle, so as to be subservient to each other."

Whether photographic pictures will ever be produced in their natural colours, is a question which cannot yet be determined. The circumstance that the rays by which photographic pictures are produced, are *dark* rays, distinct from the colorific rays, would appear to be unfavourable to such a result. It appears, however, that Sir John Herschel has succeeded in obtaining coloured pictures of the prismatic spectrum in light colours on a dark ground; he is "not prepared to say that this will prove an available process for coloured photographs, though it brings the hope nearer."

The circumstance that the focus of the colorific rays is not the same as that of the photographic or chemical rays, is a difficulty in the way of the photographer. In setting his camera, he may obtain a perfect optical image by means of the luminous rays which he can see, but this image will not correspond with that formed by the chemical rays which he cannot see. In order to produce a picture in focus, the object-glass must be moved through a space equal to the distance between the foci of the colorific and the photogenic rays. In order to enable the photographer to make this adjustment, instruments named *focimeters* have been constructed. In one by M. Claudet, there is placed before the camera at the same instant, a circular arrangement of cards formed into segments, each segment being at a different distance from the lens. A photographic picture of all these segments is at once produced, and the picture of one of them will be found to be more distinct than all the others; consequently, the plate or paper is in the photogenic focus which corresponds with that one. Mr. G. Knight determines the photogenic focus by placing the photographic plate or paper in an inclined groove, so that different parts of it are at different distances from the lens; a printed sheet is then placed before the camera, and in the resulting picture, some parts of the print will be much more distinct than others, and thus that point of the plate, or of the inclined groove, which corresponds with the photogenic focus, is determined.

A remarkable method of obtaining pictures by the agency of light, was discovered some years ago by M. Moser, of Königsberg. He has established the fact that light constantly emanates from all bodies, even in complete darkness; and that when two bodies are placed near each other, the one impresses upon the other a picture of itself. In this way, true photographic pictures are formed, engravings copied, &c.; but they are invisible, and continue to be so until developed by the action of certain vapours, such as vapour of water, mercury, iodine, &c. If a sovereign be placed on a piece of ground glass on a warm mantelshelf, and be left for half-an-hour, a beautiful image may be developed, by simply exposing the glass to vapour of mercury.

Such is a brief outline of the delicate and beautiful art of photography. The processes are subject to considerable variation in the hands of different professors and scientific men; these the amateur will find detailed in treatises devoted to the subject, and will be able by experience to decide upon the methods best adapted to his means and manipulative skill.

The art of photography received abundant illustra-

tion in the Great Exhibition, but rather as a *fine* art than a *useful* art. There were portraits, views and landscapes in abundance, but no specimens of copies of ancient inscriptions; no delineations of natural objects, with the view to illustrate natural history; no enlarged representations of the microscopic products of nature, or of the dissected parts of plants and animals; scarcely an attempt to show the action of the actinic spectrum on chemical preparations, or on natural colours; no impressions of the lines in the photographic, corresponding to those in the luminous spectrum; no copies of pages of ancient manuscripts; no miniatures of printed books, &c. It is well remarked in the Jury Report, that "photography holds a place at present intermediate between an art and a science, a position eminently favourable to development in either direction. Its pursuit as an elegant and most extensively useful art, affords a strong motive for inquiry and experiment in the improvement of its processes; in the course of which, an infinity of facts, new and unexpected, come forward, every one of which may turn out to be the embodiment of some pregnant scientific principle; nay, even the smallest minutiæ of manipulation, on which it is found that success or failure in the production of artistic effect depends, may, if duly observed and reasoned on, afford indications, linking together the known and the unknown in optical science, and tending to bring these mysterious operations of light within the pale of exact reasoning. On the other hand, science is too much in the habit of repaying to art, with interest, every assistance of that nature, to leave room for doubt of similar results in this instance, when once the principles of operative chemistry shall have assumed a definite form and subjective connexion. It is this which affords us full assurance that photography is yet in its infancy, and that all which has been hitherto accomplished—marvellous and exquisite though it be—is as nothing to what will be performed when the veil shall be removed, which, for the present, obscures its true scientific principles." The rapid advance of the art during the brief period of its existence, is well illustrated by the fact, that the method formerly adopted for procuring daguerreotype portraits required a person to sit without moving for 25 minutes, in a glaring light, whereas, at the present day, the effect is produced almost instantaneously.

The introduction of the accelerating process by M. Claudet, at once improved the practice of portrait-taking; two daguerreotype establishments were formed in London, and although the portraits taken were deficient in expression and had other defects, yet the receipts at these establishments several times amounted to £60 in one day. The use of Mr. Talbot's Calotype process for portraits, by Mr. Collen, was a further improvement in this branch of the art; and as the effect of the picture could be heightened by the brush, defects of expression could be removed, and the likeness improved, at subsequent sittings.

During a portion of the months of December 1852 and January 1853, the Society of Arts, London, held an exhibition of photographs, collected from the most distinguished artists and amateurs in this country, and some from continental artists. The specimens exhibited exceeded 1,000 in number, and afforded a very favourable idea of the condition of the art at the time. On the 26th January, Mr. Glaisher read a paper to the Society, "On the chief Points of Excellence in the different Processes of Photography, as illustrated by the present Exhibition." The following observations are abridged from the printed report of this lecture. Of the various photographic processes now in use the range of practice assigned to the *calotype* has been very general, with a leaning, however, to outdoor and local scenery. That of the *wax-paper* has been more strictly defined; and on the Continent we find it employed in architectural designs, and fragments of carved and massive ornamentation. In England it has been chiefly employed to perpetuate the passing scene, with little discrimination as to its character. The *albuminised glass* has been applied to general representation, such as views, landscapes and groups of statuary. The *albuminised paper* has also been employed upon groups of statuary. The *collodion* has furnished designs of various character, including the whole of the portraiture in this exhibition. Some of the effects of the collodion process are so admirable, and the points of failure in all so much less exaggerated than those either of paper or albuminised glass, that this appears to be the process which ought to be specially cultivated: it generally exhibits a natural interpretation of the lights and shadows, which rarely fails to communicate a similar effect to the subject. In fact, this process is less eminent in failure, and more eminent in success, than the other processes illustrated in the exhibition, for it combines the excellencies of our best photographs, with fewer of their defects.

The difficulties of representing woodland and forest scenery were evident in this exhibition: the tree, whether alone and filling the central area of the picture, or one of several, is more imperfectly represented than any of the many creations of art and industry. Very few of the trees are perfect in definition towards the top and outer branches, arising from their continued stirring with the motion of the air. In the same manner the gentle movements of the leaves in summer tend to produce confused results. A more sensitive medium than the paper is required, upon which to obtain an instantaneous impression. This want may probably be supplied by the collodion, or by Mr. Talbot's instantaneous process.[1]

The representation of running water is a difficulty that points also to a highly sensitive process, and an

(1) It appears from recent experiments, that the exposure of the prepared surface to the optical image for an instant is sufficient to produce a perfect photographic picture. A printed paper was attached to the face of a wheel, and this was made to rotate. The camera with the prepared photographic surface was placed opposite to the wheel and properly adjusted, and then the room was darkened. The wheel was next illuminated for an instant by a strong spark from the conductor of a powerful electric machine, and this instantaneous appearance of the wheel before the camera was sufficient to produce a perfect picture.

instantaneous impression. In a water-mill on paper, the water descending in a body from the trough above the wheel gives the idea of a soft and rounded mass, the apparent rotundity being conveyed by the shadow which rounds the edge; the characteristics of water as exhibited under any circumstances are totally lost. In short, quickly running and ruffled water in the present collection has not been in any case depicted with satisfactory results.

Paper appears to be well applied to subjects of no great finish and delicacy, and its general tone is to be preferred to that of wax-paper. The latter is most frequently recognisable by great strength of tone and by the prevalence of a citrine hue, which is very objectionable in excess. This process seems to exceed the paper in the power of discriminating material, and some of the finest specimens in the collection are due to its employment.

The glass processes, either by albumen or collodion, appear to be best fitted for conveying subjects of a smooth and delicate nature. The specimens exhibited showed the greatest finish and delicacy, and it is thought that the collodion will supersede the albuminised glass.

Many of the photographs are wanting in verticality, in consequence of not properly adjusting the visual axis of the camera. The camera ought to be furnished with a spirit-level to secure horizontal adjustment in the field with facility and certainty. In some cases indifferent object-glasses appear to have been used, and in some others, where the object-glass has been good, it has been so ground as to give good definition within very narrow limits.

"Whether photography will ever exist as an independent art, without assistance borrowed from the artist, is a matter of pure speculation. At the present time there is much to be done before this most graphic process can approach within even near limits to the beautiful semblances of nature which are preserved in the works of our best artists. It is necessary that the photographer should receive a better artistic education; that he should be better acquainted with those laws belonging to science by which the canvass is made to assume the semblance of some of nature's most agreeable effects: it is necessary that he know how to choose his point of view; to decide upon the proper balance of light and shade; to have a correct appreciation of the strength of outline and development of parts belonging to the distances of his picture; that he should not resort to violent contrasts for effect, and that he should choose that tone most in accordance with his subject. The true knowledge of these, among other things, must belong to the photographer who would step beyond the level of ordinary practice. To the artistic spirit infused into the Photographic Society, so newly organised, we must look for his better guidance in reference to those points of study; but with all its imperfections, photography may be considered as sufficiently under control to be rendered a subsidiary and highly useful art." In the present collection there are indications of its application to the microscope, and to the medical profession in the portraits of persons afflicted with mental disease; admirable copies of engravings were also shown, and a few illustrations of tropical scenery.

In conclusion, we may just refer to the application of Mr. Wheatstone's beautiful instrument, the stereoscope, to photography; to the attempt to transfer the collodion picture from the glass to the wood engraver's block; and to the success which has long attended the use of sensitive paper in furnishing a sort of perpetual register of meteorological and magnetic instruments.

PHOTOMETRY is the art of measuring the relative intensities of different artificial lights. The variations in the intensity of light cannot be measured by an instrument in a manner similar to that by which variations in temperature are measured by the thermometer, or in the pressure of the atmosphere by the barometer. Although the quantity of light which falls upon the earth differs greatly at different times, depending upon the height of the sun above the horizon, upon the presence or absence of clouds, and the state of the atmosphere, yet we have no means of comparing days together with respect to their light, as we are accustomed to do as regards their heat. We have no instrument or contrivance by which light alone can be made to produce mechanical motion, so as to mark a point on a scale, or to give a direct reading off of its intensity or quantity at any moment. "This obliges us to refer all our estimations of the degrees of brightness at once to our organs of vision, and to judge of their amount by the impression they produce immediately on our sense of sight. But the eye, though sensible to an astonishing range of different degrees of illumination, is, partly on that very account, but little capable of judging of their relative strength, or even of recognising their identity, when presented at intervals of time, especially at distant intervals. In this manner the judgment of the eye is as little to be depended on for a measure of light as that of the hand would be for the weight of a body casually presented. This uncertainty, too, is increased by the nature of the organ itself, which is in a constant state of fluctuation: the opening of the pupil, which admits the light, being continually contracting and expanding by the stimulus of the light itself, and the sensibility of the nerves, which feel the impression varying at every instant. Let any one call to mind the blinding and overpowering effect of a flash of lightning in a dark night, compared with the sensation an equally vivid flash produces in full day-light. In the one case the eye is painfully affected, and the violent agitation into which the nerves of the retina are thrown, is sensible for many seconds afterwards, in a series of imaginary alternations of light and darkness. By day, no such effect is produced, and we trace the course of the flash, and the zig-zags of its motion, with perfect distinctness and tranquillity, and without any of those ideas of overpowering intensities which previous and subsequent total darkness attach to it. But yet more. When two unequally illuminated objects (surface of white paper, for instance)

are presented at once to the sight, though we pronounce immediately on the existence of a difference, and see that one is brighter than the other, we are quite unable to say what is the proportion between them. Illuminate half a sheet of paper by the light of one candle, and the other half by that of several, the difference will be evident. But if ten different persons are desired, from their appearance only, to guess at the number of candles shining on each, the probability is that no two will agree. Nay, even the same person, at different times, will form different judgments. This throws additional difficulty in the way of photometrical estimations, and would seem to render this one of the most delicate and difficult departments of optics."[1] The eye is, however, able to judge with tolerable accuracy of the equality of two lights, or of two degrees of illumination seen at once. Thus, in order to ascertain the relative quantities of light furnished by two different lamps, place two discs of white paper a few feet apart on a wall, and throw the light of one lamp upon one disc, and the light of the other lamp upon the other disc: if the lamps are of unequal illuminating power, the lamp which affords most light must be moved back until the two discs are equally illuminated. Then on measuring the distance between each lamp and the disc which it illumines, the luminous intensities of the two lamps may be calculated. As the intensity of light from a point or luminous source diminishes inversely with the square of the distance, [see LIGHT. See also HEAT, Fig. 1135,] so the intensities of the two lamps are to each other as the square of the distance. If, when the discs are equally illuminated, the distance from one lamp to its disc is double the distance of the other lamp from its disc, then the first lamp is 4 times more luminous than the second; if the distance be triple, it is 9 times more luminous, and so on.

In this experiment the eye cannot judge very accurately as to the exact degree of equality in the light thrown upon the two discs; but by means of two conical tubes, Fig. 1616, united at their smaller ex-

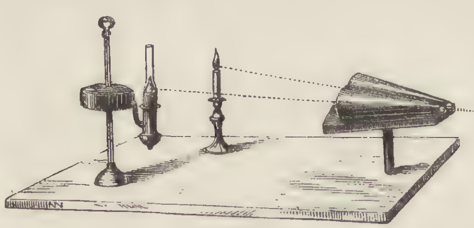


Fig. 1616.

tremities, and terminating there in two discs of paper, it is more easy to decide when the discs are equally luminous. If, for example, it is desired to compare the light of a candle with that of a lamp, in order to ascertain how many candles will give a light equal to that of the lamp, the two lights are placed so far apart that their rays shall not interfere, the broad end of one of the tubes being directed to the lamp, and that of the other tube to the candle. The lamp is drawn back, or the candle moved forward, until the two discs are equally luminous. The distances are then measured as before.

A still better arrangement than the above was contrived by Professor Ritchie, and is shown in section, Fig. 1617. It consists of a rectangular box, open at both ends, and blackened within to absorb

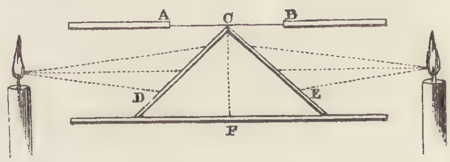


Fig. 1617.

extraneous light. At the top is a long narrow rectangular slit, A B, covered with tissue or oiled paper. Within are two pieces of looking-glass, C D and C E, cut from the same piece, in order to secure uniformity of reflection. Each mirror is of the width of the box, and its reflecting surface is turned towards the open end of the box. The upper edges of the mirrors meet at C, and the line of junction divides the space A B into two equal parts: it is moreover covered with a piece of black card, to prevent the mingling of the lights reflected from the two mirrors. In using this *photometer*, as it is called, it is placed between the lights, the intensities of which are to be compared, so that they may be reflected from C D and C E, upon the tissue paper A B. The instrument is then brought nearer to one or other of the two lights, until, to an eye placed above A B, the two portions A C, B C, appear to be equally illuminated, which may be judged of with tolerable accuracy. The distances must be measured from the vertical C F. In viewing the illuminated surface A B, the eye should be protected from extraneous lights; for which purpose a prismatic box is provided; it is about eight inches long, and blackened within to absorb shining light. One end of this box is to rest on the illuminated surface A B, and the other is to be applied close to the eye. Instead of using the mirrors and the paper screen A B, the inclined planes, C D, C E, may be covered with white paper, and viewed directly through the aperture. But however the instrument be used, a mean of several observations should be taken, the box being turned round after each. When the lights compared are of different colours, as daylight, moonlight, and candlelight, the space A B is to be covered with a piece of fine white paper, printed distinctly in a small type; the paper is to be brushed over with oil, and the box being placed between the lights, it is to be moved until the printing can be read continuously along the paper, with equal ease on both sides of the line C. Or the printed paper may be pasted on the mirrors, or the inclined surfaces on which they rest, and the print is then to be read through the opening, which may be enlarged for this method of applying the box.

Professor Wheatstone has constructed a photo-

(1) Herschel, *Encyclopædia Metropolitana*, article LIGHT.

meter of greater accuracy and convenience than any yet contrived. It depends for its action on the permanence of the impression of light upon the optic nerve, and is thus described by Professor Daniell:— "If a small convex reflector, such as a bead of glass, about $\frac{1}{8}$th inch in diameter, silvered on the inside, be placed between two lights, bright images of both will be formed, but differing in brightness according to the intensity of each. A rough estimate of their relative values may be obtained by adjusting the distances between the two; but by causing the bead to move backwards and forwards in a straight line, two parallel lines of light will be formed, about $\frac{1}{10}$th inch apart, instead of two spots. By moving the reflector to different parts of the line which joins the two lights, or by changing the relative distances of the lights themselves, these two luminous lines may be made to appear perfectly equal in brightness. The comparative value of the lights may then be ascertained by squaring the distances."[1] In Fig. 1618 the instrument is represented of the full size. C c′ c″ is a circle of brass fixed to the wooden frame F; the inside of the brass circle is toothed, so that a smaller circle, *c c″*, half the diameter of the larger one, and toothed at its circumference, may engage the teeth of the larger circle. The small circle turns upon its centre *c′*, and is fixed to the arm *a c′*, which is moveable upon the centre *a* of the large circle by means of a key on the opposite side of the frame. The bright metallic bead *b* is attached to the circumference of the small circle, and as this circle is carried round by the arm *a c′*, it also rotates rapidly upon its centre *c′*, and the bead travels along the diameter of the large circle from *b* to C in completing one half of its revolution, and back again from C to *b* during the other half.

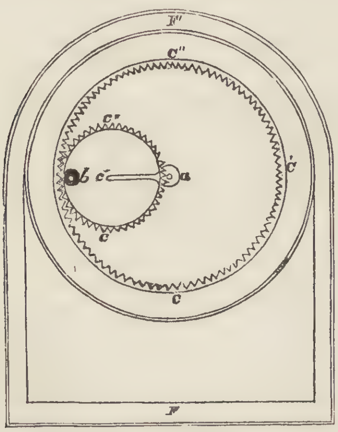


Fig. 1618.

Count Rumford devised a method of comparing the intensities of two lights by means of the shadows which they respectively cast. The two lights are to be so arranged that each may cast upon a plane white surface a shadow of a small object, such as that of a book or an upright rod, as in Fig. 1619: the eye can form a tolerable judgment as to the relative darkness of these shadows. The brighter light, which casts the deeper shadow, is to be removed, or the weaker light brought nearer, until the two shadows are equalized. The distance of the two lights from the object which intercepts their rays being measured, the relative intensity of the lights will be, as before, inversely as the squares of the distances. The shadow of one light is illuminated solely by the rays of the other, while the surrounding space is illuminated by the rays of both; when, therefore, the shadows are equal, the lights are equal. Count Rumford applied this method to measure the variations in light, by a candle left unsnuffed. Supposing the light furnished by a properly snuffed candle to equal 100, and it be allowed to burn for 11 minutes, the light will then be equal to only 39, and if allowed to burn without snuffing for 30 minutes, it will only be equal to 16.

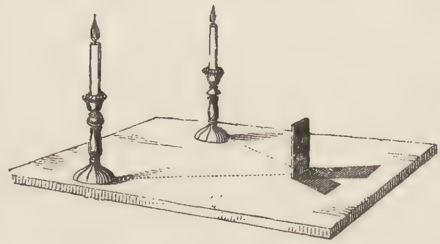


Fig. 1619.

Professor Leslie's photometer is constructed on the assumed principle that light is convertible into heat. It consists of the differential thermometer, of which one of the bulbs is blackened and the other clear: a glass case is put over the instrument to exclude rays of heat. In order to use it, the light to which it is exposed passes through the clear ball, but is absorbed by the black, and supposing this light to be converted into heat, the rise of temperature will indicate the degree of illumination. The instrument is certainly not correct in principle; it is in fact nothing more than a delicate air thermometer.

A simple and ingenious photometer in use at the Westminster Gas-works, consists of a disc of paper, 4 or 5 inches in diameter, the outer portion of which is waxed, and the inner portion left plain, so that on holding the paper vertically between the eye and a luminous flame, the waxed portion is seen in the form of a translucent ring, while the unwaxed portion appears as an opaque disc. The disc is mounted vertically upon a short cylinder of wood, sliding in the groove of a horizontal frame, at the extremities of which are fixed the lights to be compared. This frame also contains a scale graduated into feet and inches. The sliding piece which carries the disc is also furnished with a pointer, so that the distance of the disc from either flame can always be ascertained at a glance. In using this apparatus, the observer stands on one side in such a position as to get the disc fairly between his eye and one of the flames. The waxed ring is then illuminated by the transmitted light of the concealed flame, while the reflected light of the front flame illuminates the opaque disc. The paper is then moved to and fro until the transmitted

(1) Chemical Philosophy. Second Edition. 1843.

light and the reflected light appear to be equal. When this is seen to be the case on one side, the observer passes to the other, where the conditions are reversed, but the result is the same; the light which on the other side lighted up the opaque disc, now illumines the waxed ring, and *vice versâ*. The distance of the paper from either light is then measured, and the power of each flame is calculated as before.

PIANO-FORTE. This well-known instrument belongs to that class of stringed instruments in which the sounds are produced by imparting vibration to elastic strings extended tightly over a case or box, and covered with thin boards, the vibrations of which, imparted to the volume of air which they enclose, assist the development of sound.

It is remarkable that while poetry, architecture, sculpture, and probably painting, attained their highest state of perfection among the ancients, it has been reserved to the moderns to achieve excellence in music; and the cause is closely connected with the superior mechanical skill of the moderns. If the progress of instrumental music depend upon the perfection of the mechanism of the instrument which gives it voice and meaning, music, as a fine art, must be in a more advanced state now than at any other period, since our mechanical resources were never at any former period so great, or so fully developed. The music of the old composers exhibits, in a very marked degree, the capabilities of the instruments for which it was written, and these were so limited, that to attempt to perform one of the modern first-class compositions on a piano-forte made forty or fifty years ago, would be like one of the old stage-coaches attempting to compete with a railway-train.

The old composers, in writing their orchestral and concerted pieces, availed themselves in their studios of such instruments as spinets, clavichords, harpsichords, and afterwards of piano-fortes. These were but feeble instruments, but the use of them by men of genius "led to the peculiar capabilities of the piano-forte being thoroughly studied and appreciated; and the composers repaid their obligation to the instrument by writing for it many of the very finest productions in music, and by practising the execution of these productions to such an extent as to be able to bring them before the public with the greater *éclat*. The importance which the instrument had thus gained led from time to time to its improvement and enlargement; and this again to still finer compositions being produced for it, and to the adaptation for the piano-forte of all the best orchestral compositions; so that the advance of the art, and the improvement of the piano, have had a mutual effect upon each other, until it is now beyond all question the first of musical instruments, both to the profession and to the cultivated classes of society."[1]

The instruments which immediately preceded the piano-forte were extremely simple in their mechanism, and imperfect in their action. The clavichord consisted of a piece of brass pin wire *b*, Fig. 1620, placed vertically in such a position, that on pressing down the key *k* it would strike or press against the string *s*

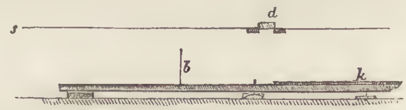


Fig. 1620. THE CLAVICHORD.

just above it: the portion of the string to the left of *d* was free to vibrate, the other portion being muffled by a piece of cloth, which also stopped the vibrations of the whole string as soon as the finger was removed from the key. The string was both struck and pressed by the wire *b*, and the sounds produced were of a soft melancholy character.

In the *spinet* the string was struck by means of a piece of crow or raven quill, (hence the name of the instrument, from *spina*, a thorn or quill,) attached to the tongue of a little implement termed a *jack*, which rose vertically from the further end of the finger-key. The jack *j*, Fig. 1621, was made of pear-tree wood, and the tongue *t*, through which the piece of quill *q* was passed, moved upon a swivel. When the key was pressed down the jack moved upwards, and the quill was thus forced past the string, its own elasticity giving way; and the quill remained above the string so long as the finger was pressed upon the key, thus allowing the string to vibrate. On removing the finger from the key the jack returned to its place under the string, and the tongue, thrown back in passing the string, was forced into its perpendicular position by the spring of a bristle *s b* behind it, so that the quill opposed very little resistance: at the same time a small piece of cloth, fixed in the top of the jack, rested on the string and served as a damper.

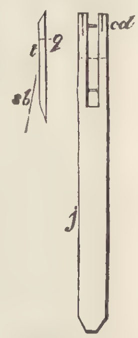


Fig. 1621.

The spinet had but a single string to each note. When two strings to each note were used, the name of the instrument was changed into that of the *harpsichord*, or horizontal harp. The strings were still vibrated by means of quills, although from their rapid wear, and the number of hours required to re-quill an instrument, other elastic substances, of a more durable nature, were tried, such as ivory and leather; but the instrument is said to have lost in sweetness by the change.

The idea of making the jack *strike* the string instead of pulling it, gave birth to the piano-forte. The value of this idea seems to have been at once, and so extensively appreciated, that the originator of it is lost in the crowd of appropriators. Germans, French, and English, all lay claim to the invention, and although it is scarcely more than a century old, the date of its birth is as obscure as its country. We have met with a notice of a *hammer-harpsichord*, as it is termed, as early as 1711, with reference to the *Giornale d'Italia* for that year for a description of it. It is stated that the touch and mechanism of one that was brought to England were so imperfect, that nothing quick could

(1) M. Thalberg in the Jury Report.

be played upon it, but that the "Dead March in Saul," and other slow music, had a fine effect. In the instrument named the *virginal*, the strings were struck with hammers consisting merely of the addition of a leather button to the top of a piece of strong wire screwed into the further end of the finger-key. The great defect of this simple hammer was, that it did not instantly quit the string when it had struck the blow, so that the sound was deadened. This defect is said to have been remedied by one Christoph Gottlieb Schroeter, of Hohenstein, on the borders of Bohemia, who in 1768 published an account of his instrument, in which it is declared that "the performer can play *piano* or *forte* at pleasure," whence is said to have originated the name of the instrument.

More than 20 years before this, however, the instrument is mentioned by name, on the occasion of a visit made by John Sebastian Bach to Frederick the Great of Prussia, in 1747, when it is recorded that the king was so pleased with certain *forte pianos* manufactured by Silberman of Freyburg, that with royal profusion he purchased them all (15 in number), and placed them in different rooms of his palace. On Bach's arrival the king passed the evening in hearing the great musician play. These instruments do not, however, appear to have maintained their reputation, for it is stated that eighteen years later, viz. in 1765, the king ordered a harpsichord of the best kind from the most celebrated maker of the day, viz. Tschudi of London, the predecessor of Broadwood and Sons.

The piano-forte was not known in England until about 1767, when it was introduced on the stage of Covent Garden Theatre as "a new instrument," as appears from the evidence of a play-bill of the period, in the possession of Messrs. Broadwood. The harpsichord makers of the day became manufacturers of the new instrument, and a German, named Backers, became celebrated as a maker. The name-board of a grand piano by him is still in existence with the date 1776. His contemporary, Zumpe, introduced some important improvements, and he was followed by others, many of whose names, such as Kirkman, Broadwood, Stodart, Pohlman, Beck, Clementi, &c., are still held in respect, or still represent important firms in London.

There are three forms of piano-forte, viz. the *grand* and the *square*, in which the strings are placed in a horizontal position; and the *upright*, in which the strings are vertical.

The form of the *grand* piano is the same as that of the harpsichord, and was suggested by the varying length of the strings. This form is well adapted to the introduction of the best kinds of mechanism, and is always chosen for first-class instruments. Each note is produced by the simultaneous vibration of 3 strings; but in order to lessen the cost of the instrument, a form of grand piano has been constructed in which there are but 2 strings to each note; such are the *bi-chord* and *semi-grand*. There are also *boudoir*, or *cottage-grands*, which have shorter strings and occupy less room.

The form of the *square* piano is oblong rectangular, the same as the German clavichord, and is probably the first shape in which the piano appeared. It remained an inferior instrument until the mechanism of the grand was introduced into it, thus leading to the variety called *grand-square*. It is difficult in this instrument to strengthen the framing sufficiently, and the oblique position of the action with respect to the strings and key-board is also an objection; nevertheless this form is the best substitute for the grand.

The *upright* piano was at first a grand, set on end, raised on legs 2 or 3 feet above the ground, and struck at the lower end: this, the *upright grand*, as it was termed, was unwieldy from its great height, and was superseded by the *cabinet*, in which the frame was brought down to the ground, and the blow given at the upper end of the strings by means of levers and long vertical rods communicating from the key to the hammer. It formed an elegant piece of furniture, and continued long in favour. Still, however, its great height (6 feet) and length of action were unfavourable to delicacy and ease of touch. About 1812 Mr. Robert Wornum introduced an upright piano-forte, the height of which was from 4 to 5 feet: this was the *harmonic*, a name afterwards changed to *cottage*. In 1827 its height was still further reduced to 3½ feet from the ground, forming the *piccolo*, which served as the model for many others of different names and about the same size.

The *compass* of the piano was originally 5 octaves, from F below the lowest note of the violoncello, to the fifth F above. This was extended upwards to C, making 5½ octaves, forming what were termed piano-fortes "with additional keys." As the mechanical resources of the manufacturer became enlarged, and the music written for the instrument improved, another half octave was added to F in the same direction, and afterwards, in the better class of instruments, half an octave was added in the bass down to C. Another note was next inserted in the treble; and thus the compass came to be from CCC (on the organ 16 feet C) to G, or 6½ octaves. After this another note was added, raising the scale to A. Grand pianos now have 7 octaves, from A to A or G to G. In the Great Exhibition was an instrument by Mott with 7½ octaves, and another by Pape, of Paris, with 8 octaves. In such cases the increased dimensions of the sound-board are favourable to the general increase in the power and tone of the instrument.

The manufacture of a piano-forte is naturally divisible into four distinct classes of operations:— I. Those relating to the *framing* and *sound-board*. II. The *stringing*. III. The *keys* and the *action*. IV. The ornamental or other *case*, covering and enclosing the whole.

I. When it is considered that the tension of the strings in a full-sized grand piano amounts to about 25,000 lbs., or between 11 and 12 tons, it will readily be conceded that the *framing*, which serves as a strut or stretcher between the two ends of the system of strings, so as to keep them apart, must be of great importance to the durability of the instrument, and

its power of standing in tune. In the old instruments the framing was of timber only, and the strings being formed into loops at one end, were secured by studs driven into a solid block of wood, named the *string-block;* while the opposite extremities of the strings were wrapped round a series of iron pins called *wrest-pins,* inserted into another block named the *wrest-plank.* The string-block and the wrest-plank were separated by a strong framing of carpentry, but this, from the very nature of the material, was insufficient to resist the enormous strain, and in gradually yielding, the instrument went out of tune. A defect of this kind, of course, made it impossible to attempt to improve the power and tone of the instrument by the introduction of stouter strings, for that would have aggravated the evil; but the makers were compelled to use light strings, and be satisfied with truth rather than power and depth of tone. At length, however, the influence of the civil engineer extended itself to this branch of industry, as it had already done, or was doing, to nearly every other: cumbrous machines of wood were every day being superseded by the lighter, more elegant and efficient structures of metal; and as the demand for metal increased, improved methods of smelting and of working it were discovered, new tools and appliances were invented; the suggestions of science soon ceased to be impracticable when working engineers, abundance of metal at a cheap rate, and intelligence in its application, grew and multiplied.

The use of metal in the framing of the piano gave the requisite strength. The studs on which the back ends of the strings were secured, were attached to a plate of wrought-iron, called the *string-plate,* curved to the form of the hollow side of the instrument; from this bars of wrought-iron or steel extended, longitudinally, above the strings and parallel with them to the wrest-plank, the ends of these bars being so firmly connected with the string-plate and wrest-plank as to sustain nearly all the tension of the strings. The string-plate was screwed firmly down to the timber framing below, and the bars were also secured thereto at intervals, whereby great strength was obtained. The more important parts of the wood framing were of the soundest oak, dried and glued up in several thicknesses. In the grand piano the wood framing under the strings is severed across to allow the hammers to rise, and in order to convey the thrust across this opening, small thin arches of metal are interposed, abutting on one side against the wrest-plank, and on the other against the transverse rail, forming part of the main body of the framing, and called the *belly-rail.* The arrangements of metallic bracing are, however, varied by different makers.

The surface of wood lying immediately under the strings is called the *sound-board;* it is formed of thin boarding, of the best Swiss pine, quite free from knots and flaws; it is cut in a particular direction of the grain, and is strengthened on the under side with small ribs: the edges are attached to the framing of the instrument so as to leave the whole of the middle portion free to vibrate under the impulse of the vibrating strings. The tone of the instrument greatly depends on the sound-board.

In *square* piano-fortes the strengthening is effected by bolting the wrest-plank and string-plate firmly down to a strong bed of timber, which extends beneath the keys over the whole surface of the instrument. In addition to this, one or two metal bars are stretched across from the string-plate to the wrest-plank, over and parallel with the strings.

In *upright* pianos the framing is most simple, on account of the continuity not being broken. The tension is maintained by means of timber struts placed vertically at the back of the instrument, to which the string-plate and wrest-plank are firmly secured. Iron bracing is also adopted.

II. The *stringing,* as already noticed, was formerly much thinner than at present. Steel wire was employed for the treble, and brass wire for the bass. The length of the instrument did not give sufficient length to strings of ordinary thickness for the lowest notes: the strings were therefore increased in thickness by lapping brass wire with a thinner one of copper. Each string also consisted of a separate wire, twisted at one end into a loop and passed over a stud in the string-block, and the other end wrapped round the wrest-pin. When heavier wires came to be introduced, capable of resisting a heavier blow from the hammer, this method of stringing caused the strings to jar against each other: besides, it was difficult to loop heavy strings. This led to the plan of making one wire of double length serve as two strings, by bending the middle of the wire round a pin in the string-plate, and the two ends round wrest-pins at the opposite end. This method was patented by Messrs. Collard, 1827.

As the instrument increased in power, brass wire was found to be too soft and weak, and steel wire came to be solely used. For the lowest octave of the bass notes lapped wire is used, the main wire being of steel, and the lapping wire of soft iron for the upper part of the octave, and of copper for the lower. The lapping is now made quite close, instead of open, as formerly. For each of the lowest bass notes of the grand piano two strings are sufficient, and sometimes only one.

In the stringing of grand pianos another improvement was introduced, viz. that of the *upward bearing* of the strings at the striking end. The length of the vibrating portion of each string is determined by two bridges, one attached to the sound-board, and the other to the wrest-plank a little in front of the striking point of the string. Now supposing the strings to bear down on these bridges, and the strings to be struck from below, the tendency of the blow would be to lift up the strings from their bridges, and for the moment to increase their effective vibrating length, which would obviously interfere with the purity of the tone. By reversing the direction of the bearing of the front bridge, or by substituting for this bridge a plate pierced with a series of holes through which the strings were passed, turning up immediately to the wrest-pins, each string would

evidently have an upward bearing at the front end, and the effect of the blow would be to force the string against its rest, instead of lifting it off as before. This is shown in Fig. 1634.

III. We come now to the most important part of our subject, the *action* of the piano, that is, the connexion between the key-board and the strings, or, in other words, the means provided for striking the strings. The importance of the action in bringing out the elements of expression which are peculiar to the instrument, are well stated by Mr. Thalberg:—"Between the mind of the player that conceives, and the string that expresses by its sound the conception, there is a double mechanical action; one belonging to the player, in his fingers and wrists; the other to the piano, in the parts which put the strings in motion. No two piano-players touch the instrument alike; that is, no two players have the same mechanical action in their fingers, or produce the same tones; and the difference in the style and degrees of excellence of pianists is more owing to this than to any other cause. It is, therefore, self-evident, that that part of the piano which continues the action of the fingers, and completes the connexion between the mind of the player and the strings of the instrument, should have a delicacy and a power answering as near as possible to those of the hand of the player. Every difference in the action of the piano will give a corresponding difference in tone and expression; and hence this part of the instrument has at all times been justly considered of paramount importance, not only by the great professional pianists, but by the highly-cultivated amateur player."

The first action in the piano-forte, properly so called, was very defective, compared with that to which we are now accustomed. The key *k*, Fig. 1622, was the same as in the clavichord, Fig. 1620. To the key was attached a lifter *l* of brass wire, furnished at the top with a button of hide leather covered with

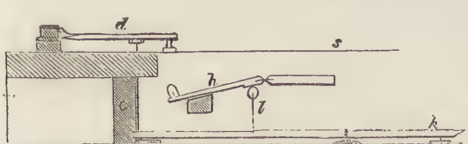


Fig. 1622. SINGLE ACTION.

soft leather. When the key was pressed down, this lifter struck the hammer *h* against the string *s*, and caused it to vibrate. At the extreme end of the key the *mopstick*, or *sticker*, *e*, raised the damper *d* at the very moment the hammer was raised to strike the string; and it is evident from this arrangement, that so long as the key was kept pressed down the string would continue to vibrate until the force of the blow upon the string were entirely expended; but the moment the finger were taken off the key, the sticker *e* would fall down with the key, bringing the damper *d* into contact with the string, suddenly arresting its vibrations. This damper was a wooden lever, lying horizontally over the strings, with a bit of cloth attached to the free end. Another form of damper is shown in Fig. 1623. It is a bent brass lever, moving upon a centre, and in its normal state pressing, in consequence of the superior weight of the lower arm *l*,

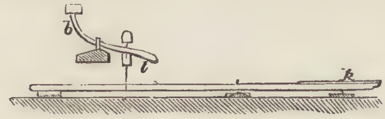


Fig. 1623. DAMPER.

against the string at *b* from below. On pressing down the key *k*, the lifter *l* will rise, thereby elevating the lower arm of the lever, and depressing the upper arm, thus setting the string free to vibrate. On removing the finger from the key, the superior weight of the lower arm will evidently cause the brass button to return to its original position. The piano-forte, thus constructed, was called the *single action:* it continued long in use, even up to the commencement of the present century. Its tone was thin and wiry, and it had this serious defect, that unless the key were struck with some considerable force, the hammer did not reach quite up to the wire, and consequently no sound was produced; and if, to remedy this, the hammer-rest, under *h*, Fig. 1622, were placed nearer to the string, there was danger of *blocking*, that is, of the hammer not leaving the wire immediately after

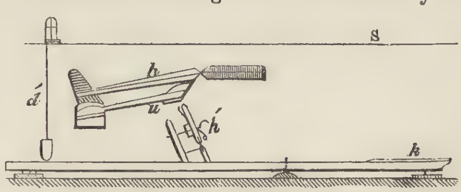


Fig. 1624. HOPPER.

the blow. To remedy this defect, the *hopper h*, Fig. 1624, was invented. This is a jointed upright piece, attached to the back end of the key, and used to lift the hammer instead of the stiff wire, or lifter. When the key is pressed down, the hopper engaging in a notch on the under side of the hammer, lifts it to within so very short a distance of the string, that a slight additional pressure causes it to strike; but in the act of pressing down the key with sufficient force to cause the hopper to lift the hammer high enough to strike, the jointed part of the hopper in rising comes in contact with a fixed button, and escapes from, or *hops* out of, the notch, and allows the hammer to fall clear away from the string. This mechanism, called *double action*, is still in use for square pianos. Fig. 1624 also shows at *d* what was long termed the *Irish damper*, from its having been invented by an

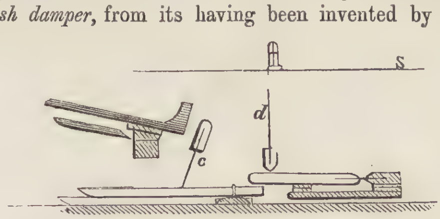


Fig. 1625. DOUBLE ACTION.

Irishman named Southwell. It was simply an upright rod with a piece of cloth at the top, which the rod

raised from the string the moment the key was depressed. This form was superseded by the *crank-damper* *d*, Fig. 1625, attached to a separate lever below.

The action of the hopper was not quite perfect. The hammer, when liberated therefrom, fell upon a rail covered with cloth, or some soft bed; but after a forcible blow, the elasticity of the string struck sent the hammer down upon its bed with such force, that there was danger of its rebounding against the string, damping the vibration and injuring the tone. This was remedied by fixing to the back end of the key a projection called a *check*, *c*, Fig. 1625, which caught the head of the hammer as it fell, and held it down until released by the pressure of the finger being removed from the key. This combination of the hammer, hopper, and check, known in England as *the grand action*, and in Germany as *die Englische Mekanik*, is shown in Fig. 1626, in which *k* is the

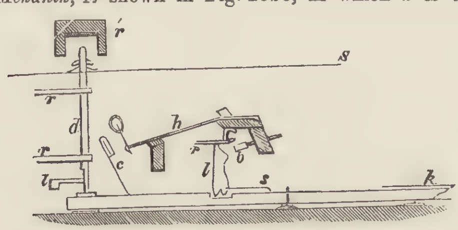


Fig. 1626. GRAND ACTION.

key, *l* the jack or lever, *b* a button for regulating the traverse of the lever, *c* the check, *d* the damper, *s* the string, *r′* the ruler, *l* the damper pedal lifter, *r r* rails and sockets, *s* the spring, and *h* the hammer.

There was still a defect in the ordinary action which required a remedy. After the hammer had fallen, it was necessary for the key to rise to its position of rest before the hopper could again enter the notch of the hammer, so as to be ready for another stroke. The consequence of this was, that a note could not be repeated without lifting the finger the whole height of the key's motion, and allowing time for the full rise before the note was struck again. This difficulty was overcome in various ways, but all the contrivances are so arranged, that while the key returns, the hammer is held up at a certain height near the string, by which means the hopper can engage itself more quickly under the hammer, and reproduce the note in less time, and with less labour to the finger than before. This, the *repetition movement*, as it was named, is shown in Fig. 1627. This, with Fig. 1628, was patented by Messrs. Broadwood for their grand action, invented by Mr. Southwell.

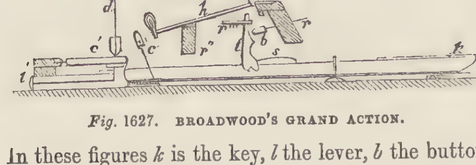


Fig. 1627. BROADWOOD'S GRAND ACTION.

In these figures *k* is the key, *l* the lever, *b* the button, *c* the check, *d* the damper, *s* the string, *c′* crank for damper, *l′* damper pedal lifter, *r r′* rails and sockets, *s′* spring, and *h* the hammer. In the repetition movement shown in Fig. 1628, *b b′* is a block passed through the hammer-butt, *s* a spring fixed at the back of *b′*, and pressing upon the front of it, the effect of which is, that when the lever passes the notch, it is caught by *b*,

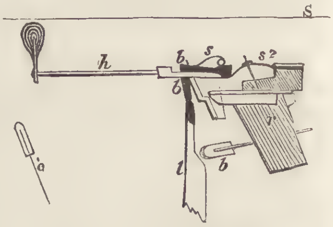


Fig. 1628. REPETITION MOVEMENT.

and the hammer is sustained at the height required. By means of another spring s^2, the action of *s′* is regulated, and the height at which the hammer shall be supported determined.

In Mr. Wornum's new grand action, Fig. 1629, the repetition is differently arranged. In this figure *k* is

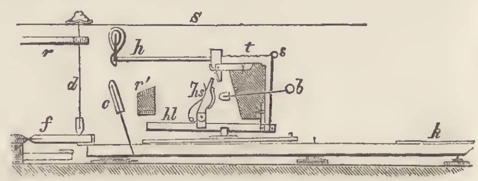


Fig. 1629. WORNUM'S GRAND ACTION.

the key, *h s* hopper and spring, *h* hammer, *c* check, *b* button to set off the hopper, *h l* hopper-lever, *t* tie attached to the butt of the hammer, *s* sustaining spring linked to the end of the tie, and fixed in the front end of the hopper-lever, the rising of which puts the sustaining spring in action. This spring gives the *piano* blow, and assists in the forte and repetition: *d f* are the damper and fixings, *r′* is the hammer ruler and back touch, below *h l* is a wooden spring to set up the hoppers.

Messrs. Collard's first grand action, the invention of Mr. James Stewart, is shown in Fig. 1630, in which

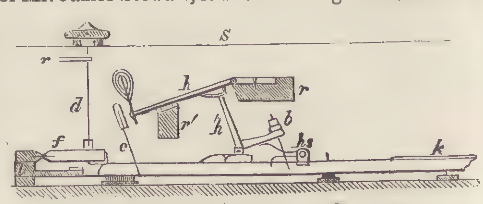


Fig. 1630. COLLARD'S FIRST GRAND ACTION.

k is the key, *h* the hammer, *r* the hammer rail, *h′* the jack or hopper, *b* the button, *h s* hopper spring, *d* damper, *c* crank for damper, *l* damper pedal lifter. The simplicity of this action is a great recommendation. Since the date of its introduction this action has been modified and considerably improved, as will be seen from the enlarged view of it given in Fig. 1631. The parts sufficiently explain themselves, but it may be useful to notice that the escapement, as it is called, which offers a point of resistance to the tail of the jack, admits of easy adjustment by screwing the little cylindrical nut up or down, so as to bring the jack into quicker or slower action: *a s* shows the jack-spring which keeps the jack up to its work under the butt of the hammer. The repeat spring is

very simply and efficiently arranged; and at the top of the check is a small projecting piece of leather marked *f*, which receives the fanciful name of *cupid's-*

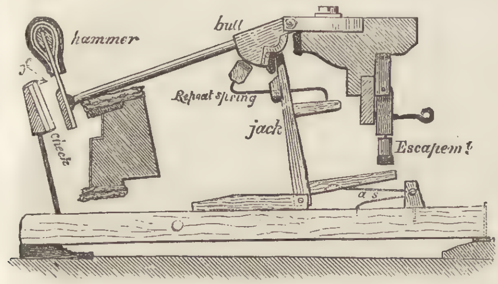


Fig. 1631. COLLARD'S GRAND PIANO ACTION.

wing, but it is sometimes called the *fly:* it is important in bringing the check into rapid action. This action, in a rather more simplified form, Fig. 1632, is applied to the best squares, named by Messrs. Collard *semi-grand squares.* It will be seen that the escapement is

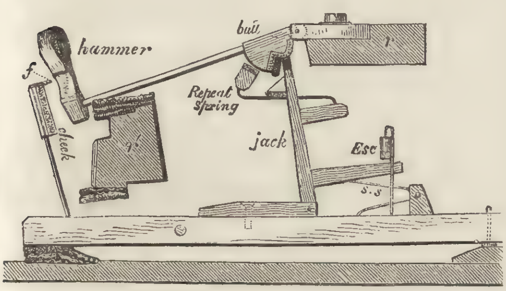


Fig. 1632. COLLARD'S SQUARE PIANO ACTION.

differently arranged, and that the hammer is in a different plane. The tip of the jack in these figures is shaded black, to indicate the plumbago with which it is rubbed for the sake of freedom of action. *r r'* are sections of rails, which, of course, extend the whole length of the key-board. In some cases, the extreme ends of the keys are plugged with lead, to cause them to fall quickly into their places, as soon as the fingers of the performer are removed from the near end of the keys.

Fig. 1633 represents an action known as *Zeiter's new grand*, in which the hopper *h* works in the key with

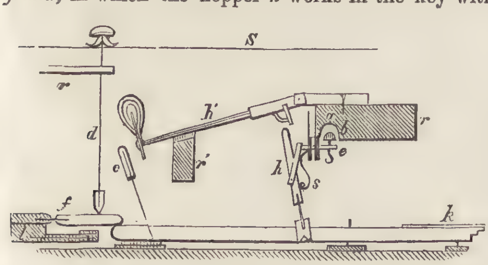


Fig. 1633.

what is called a *bird's mouth;* the escapement part of the hopper at *e* and the setting off is effected by the button *b*, working in the arched part above it *a b; s* is the hopper spring, *h* the hammer, *c* check, *d* damper, *f* damper crank, *r'* hammer rail.

Sebastian Erard's action, patented in 1821, and represented in Fig. 1634, has been the subject of considerable discussion.[1] One of its objects is to enable the performer to repeat the blow without allowing the hammer to fall down upon its bearing (a condition necessary to rapid execution), but that the key should have a perfect and uniform command over the hammer throughout its entire play, or that the note may be produced, "to use an appropriate phrase derived from steam machinery, either at *half-stroke*, at *quarter-stroke*, or in a word, at any fraction whatever of the entire stroke of the key." In this repetition action there is neither butt nor notch constructed on the arm of the hammer; but at a point placed at a certain distance from the joint on which the hammer plays, and under the arm, is attached at *b'* a small roller upon which the point of the jack *h* is directed centrically. When the key is relieved in the slightest degree from the pressure of the finger, the jack shifts its position a little under the roller, and prevents the hammer from descending. "After this, if the key be allowed to rise through the smallest fraction of the stroke, the hammer will descend through a corresponding fraction of its play, the jack always holding its position centrically under the roller, and the finger, therefore, whatever may be the extent to which the key is allowed to rise, having always a complete command over the hammer, and a complete ability to reproduce the note."

The mechanism by which these effects are produced will be understood from the figure. The key *k*, with the pivot in the usual place, acts upon the jack *l*, as in the usual mechanism. The jack *l* acts upon the hammer *h* through the medium of a combination of levers and springs. The jack *l* acts first on the intermediate lever *l*, to which is attached a second jack *h*, from which projects a rectangular arm also marked *h*. This second jack sustains the hammer by acting centrically on the roller *b'* already alluded to. When the key *k* is depressed, the lever *h l*, the rectangular jack, the roller, and the hammer, are severally raised. When the hammer-head is brought within about an eighth of an inch of the string, the end *h* of the arm of the rectangular jack is brought to bear against the fixed pin *b*, by the reaction of which the rectangular lever is turned on its centre, so as to take the head of the jack from under the roller *b'*, which is at this moment dismissed from the jack, and the hammer is projected against the string. When the hammer recoils from the string, the roller falls back upon the lever *s'*, which is urged upwards by a spring *s*, so controlled in this upward reaction by another point of contact, brought about between the spring and the hammer, that the latter cannot rebound against the string. Meanwhile the jack, no longer centrically under the roller, has passed a little to the side thereof, so as to form a tangent therewith. When the finger relieves the key slightly of its pressure, the rectangular arm *h h* is released from the action of the pin *b;* and the spring *s* acting upon the jack *h* draws it back, so as to bring it again under

(1) There is a clever article on this subject in Dr. Lardner's work, entitled, "The Great Exhibition and London in 1851."

the roller, the roller itself meanwhile being sustained with the hammer by the lever *s′* acting upon it by the spring *s*. With respect to the damper, in Erard's mechanism it is placed under the string instead of over it, and the pressure which it exercises is produced by means of a spring acting upon the lower end of the vertical rod *d*, upon which the damper is

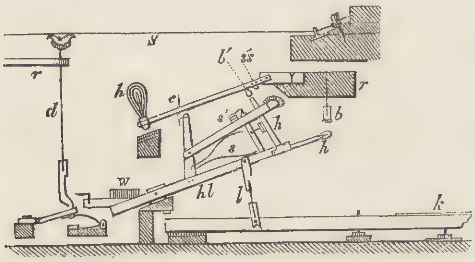


Fig. 1634. ERARD'S ACTION.

placed. When the key is depressed by the finger, the jack *l* raises the intermediate lever, the opposite end of which acts upon the damper near W by means of a shoulder formed upon it. When the short end of the intermediate lever W is thus depressed, it compresses the spring, and draws down the damper from the string. When the finger is removed from the key, the spring, relieved from the pressure of the lever, acts upon the rod of the damper, which it again presses against the string. The spring damper thus substituted for that which acted by weight, is said to have the effect of deadening the vibration more suddenly than the old form, which is liable to a jumping effect when let down upon the vibrating string.

We have now to notice the arrangement of the action in upright pianos. Mr. Wornum's *unique* piano, of which the action is shown in Fig. 1635, was only 3 feet 3 inches high, and the strings were all placed diagonally towards the floor. S is the string, *h* the hammer, *r′* the hammer rail, *h′* the hopper, *s s* are springs, *d* damper and wire, and *f* the damper rail. This form of instrument was superseded by the *double* or *piccolo* action by the same inventor. Its construction will be understood from Fig. 1636, in which S is the string, *k* the key, *h* the hopper and spring, *c* the check, *d* the damper wire, *x* setting-off screw; the upper *h* shows the hammer, and the lower *s* the hammer rail. This action has the three desirable qualities of delicacy, promptness and firmness of touch.

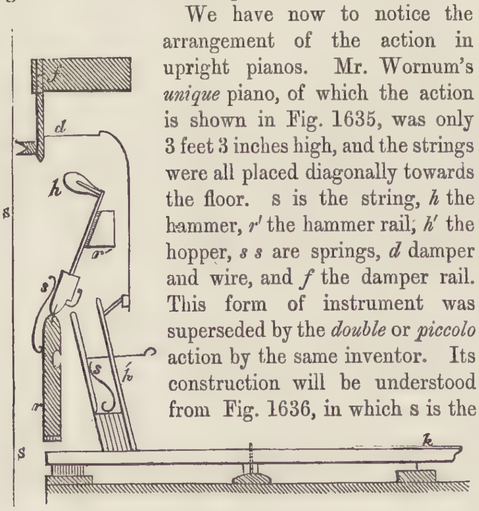


Fig. 1635. UPRIGHT ACTION.

In concluding this notice of some varieties of *action* which have been introduced into piano-fortes, there is one point requiring special notice, on account of the general misunderstanding which prevails respecting it—namely, on what does the loudness of tone in a piano-forte depend? It is generally supposed to depend on the degree of pressure with which the keys are struck. This is an error. The loudness of the note depends solely on the time taken to depress the key from the general level of the key-board; or in other words, the force of the note depends altogether on the velocity with which the hammer moves through its arc; the greater this velocity, the greater, in precisely the same proportion, will be the force of the blow given to the string, and the consequent loudness of the note. If the note produced when the hammer is raised in half a second have a certain intensity, it will have double that intensity when raised in a quarter of a second. "The finger," says Dr. Lardner, "can produce no effect whatever upon the string, except by imparting more or less projectile velocity to the hammer; that this projectile velocity depends solely on the time taken to depress the key to its bed, and that all other action of the finger, hand or arm which has not for its effect to depress the key with more or less expedition or promptitude, is just so much power wasted. The player may work his hands and arms,—he may raise them a foot high above the key-board, and throw them down again upon the keys,—he may gesticulate as though he were engaged in a herculean task, but the strings will not sympathise with his struggles, and will respond with no more effect than they would if the keys were put down with the same celerity and promptitude by the finger of an infant. It may perhaps be asked, What, then, becomes of all the force and momentum which the perspiring executant exhibits in such cases? We answer, that it is expended on the bed of the keys which receive these unavailing and ungraceful thumps, but that for all musical purposes, such force is absolutely wasted."

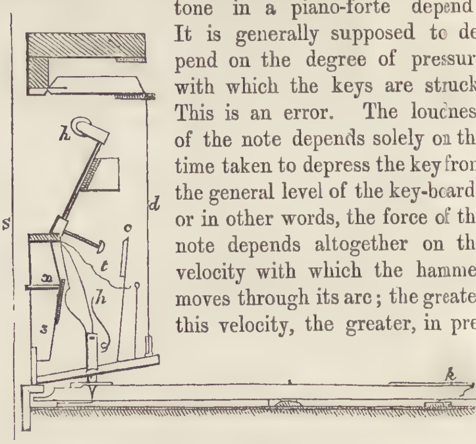


Fig. 1636. PICCOLO ACTION.

IV. The preparation of the outer case of the instrument belongs to the cabinet-maker, and will be noticed among the following statistics.

The manufacture of piano-fortes is an important branch of industry in the metropolis. In the London Directory for 1853, the names of upwards of 200 "piano-forte makers" are entered; although many of these are sellers, or retail-dealers, as they may be called. There are, however, a large number of small makers, whose names do not appear in the Directory: men who purchase the different parts of the action, the metal work, &c., of large dealers in those articles, and then put them together, much in the same way as a watchmaker combines the different parts of a watch

which he does not himself make. Some of the small dealers are, we fear, sufficiently dishonest to put the name of some eminent maker on their key-board, and thus enhance the price of the instrument. At one time, when the name of *Tomkinson* was a sort of passport to an instrument, the small dealers would put *Tomkisson* on their name-boards, and thus escape the notice of the law.

The number of subsidiary trades is also large. Although in the London Directory there are only entered 6 piano-forte *fret cutters*, 2 *hammer* and *damper-cloth* manufacturers, 4 *hammer-rail* makers, 6 piano-forte *key*-makers, 2 piano-forte *pin*-makers, 5 silkers, 1 *stringer*, and 29 tuners, yet there are a large number of persons occupied as small makers of parts of the instrument, and not being housekeepers are not entered. And even if it were possible to make this list complete, it would by no means represent the extensive subdivision of the trade. In the manufacture of a piano there are, in fact, upwards of 40 different classes of operatives employed, each of whom, with his assistants, is exclusively engaged in his own peculiar branch of the manufacture. They are particularized in the following list[1]:—

1. The *key-maker* forms the key-board in one piece, by carefully glueing up a number of pieces of well selected lime-tree wood, arranging his joints in such a way that in afterwards cutting out the keys the saw shall cut along a glue joint instead of through the solid wood. He then planes up the key-board, bores the necessary holes, glues on the pieces of ivory, scrapes and polishes them, and finally cuts the whole up into separate keys with a fine saw.

2, 3, 4, 5. The *hammer-maker*, the *check-maker*, the *damper-maker*, and the *damper-lifter-maker*, construct the parts of the action to which these names refer.

6. The *notch-maker* covers with doeskin and cloth the notches or ends of the hammer-shanks into which the hoppers work.

7. The *hammer-leatherer* covers the hammer-heads with their different coats of leather and felt, and cuts them to their proper sizes.

8. The *beam-maker* makes the mahogany beam or rail extending across the action, and covered with brass in which the hammers are centered.

9, 10, 11. The *brass stud-maker* and brass *bridge-maker* form the upward bearing-studs and bridge; and the *wrest-pin-maker* makes the iron tuning-pins.

12, 13, 14, 15. The *metallic brace-maker*, the *metallic plate-maker*, the *steel arch-maker* and the *transverse bar-maker*, all construct parts of the metallic bracing. [The makers of the iron and brass work, for piano-fortes and other musical instruments, are called *music-smiths*.]

16. The *spun string-maker* makes the lapped or spun wires.

17, 18. The *sawyer* saws the timber roughly into shape; the *bent side-maker* then cuts it more accurately to its size and thickness, and bends, by means of steam, the pieces destined to form the curved side of the instrument.

19, 20. The *case-maker* fashions, puts together and veneers the timber framing forming the principal body of the instrument; he also forms and fixes the wrest-plank. The *bracer* inserts the timber cross-bracing in the frame; but this is sometimes done by the case-maker.

21. The *bottom-maker* makes and fixes the framed bed at the lower part of the instrument, to receive the key-board.

22, 23. The *sounding-board-maker* selects the timber for, cuts out, and joints the sound-board. The belly-man planes it to its proper thickness, shapes it, finishes it, and fixes it in the case. He also forms and fixes upon it the beech bridge upon which the strings take their bearing.

24. The *marker-off* marks out the scale for the strings, fixes the pins in the beech bridge, and finishes it to its proper shape; he inserts the upward bearing bridge and studs in the wrest-plank, and bores it for the reception of the tuning pins; he also fits and fixes the metallic string-plate, longitudinal stretcher bars, and other parts of the metallic bracing, by which the piano-forte is made ready to receive the strings.

25. The *stringer* puts in the strings and fixes the wrest-pins in their places.

26. The *finisher* receives the keys and various parts of the action from their respective makers; he constructs the action-framing, puts the action together, fixes it in its place, and brings the whole of the mechanism generally into playing order.

27, 28. The *rougher-up* then tunes the instrument for the first time, stretching the strings to their proper tension; after which the *tuner* puts it thoroughly and permanently in tune.

29, 30. The *regulator of action* then examines and carefully adjusts every part of the action, and completes the regulation of the touch; and finally, the *regulator of tones* examines the tones and corrects all irregularities, making the sound of the instrument perfect throughout.

In the course of the construction of the instrument, the following operations, which relate to the exterior of the instrument, are performed:—

31, 32. The *top-maker* constructs and veneers the cover, and puts on the hinges. The *plinther* fixes and veneers the plinth.

33. The *fronter* shapes, hinges, and centres the fall or cylinder front; shapes the cheeks, makes and fixes the mouldings, puts on the locks, and attaches the ornaments.

34. The *canvas-frame-maker* makes an open wood frame-work, covered with canvas, which is fixed in the bottom of the instrument.

(1) This list was furnished by Messrs. Broadwood to Dr. Lardner at the time of the Great Exhibition. A second list from the same source gives the names of the materials required in the construction of a piano-forte, specifying the parts of the instrument where they are used. Some of the statistics are from a clever paper on piano-fortes, chiefly with reference to those of the Great Exhibition, inserted in Newton's London Journal, 1851, which has been of assistance to us in the preparation of this article. We are also indebted for information to the article Piano-forte in the Penny Cyclopædia, and to Messrs. Collard & Collard, and to several other gentlemen in the trade.

35. The *lyre-maker* makes the lyre-shaped bracket, fixed under the instrument to carry the pedals.

36, 37. The *leg block-maker* makes and fixes the blocks into which the legs are screwed; and the *leg-maker* makes the legs.

38, 39, 40. The *turner*, the *carver* and the *gilder* do all work required in their respective departments.

41, 42. The *scraper* scrapes and cleans the surface of the case, and prepares it for the *French polisher.*

The progress of the various works must not be hurried; a grand piano ought to occupy at least six months in its manufacture.

It was estimated at the time of the Great Exhibition that the number of piano-fortes manufactured in London was about 450 per week, or upwards of 23,000 per annum: that some of the largest houses made from 1,500 to 2,500 per annum each, or one-tenth of the whole: that of the annual make, between 5 and 10 per cent. might be estimated of the grand form; about the same of the square; and the remainder, forming by far the largest portion, of the upright form. The prices in plain mahogany cases were, for grands, 125 to 135 guineas; for bichord and small grands, 80 to 105 guineas; for grand squares, 50 to 100 guineas; for plain squares, 35 to 50 guineas; for cabinets, 75 to 80 guineas; for cottage and other small uprights, 45 to 70 guineas. These prices might, however, be greatly increased by employing highly carved and ornamented cases. Messrs. Collard's principal instrument at the Exhibition was valued at 500 guineas, Messrs. Erard's at 1,000 guineas, and Messrs. Broadwood's at a still higher price. By way of useful contrast to these expensive instruments, Messrs. Collard exhibited a small upright piano in a neat plain case of varnished Swiss pine or other cheap wood: they sell instruments of this class largely at 30 guineas each.

The following estimate of the value of piano-fortes annually made in London, is from the able paper last quoted:—

1,500 grands, bichords, and small grands, at, say £110 each			£165,000
1,500 squares	,,	60 ,,	90,000
20,000 uprights of various kinds	,,	35 ,,	700,000
23,000		Total value	£955,000

or nearly a million pounds sterling per annum. The number of workmen engaged in this production is estimated at between 3,000 and 4,000. The export trade is also large.

The extent of the manufacture in France is only about one-third that of England.

We are assured that this estimate is much too low for the present year, 1853. The piano-forte makers of London are not only in full employment, but are not able to keep pace with the demand. We are informed by an eminent maker who is now producing at the rate of from 40 to 50 pianos per week, that he could readily dispose of three times that number if he were in a condition to make them. A gentleman intimately connected with the piano-forte trade, has furnished us with an estimate of the produce of the various makers of Great Britain, from which it appears that about 1,500 pianos are manufactured every week, by far the larger number of which are produced in London. Of this number, 35 are grands, 20 squares, and 1,450 uprights of all kinds, including cabinets, cottages, semi-cottages, and piccolos. Of these varieties, cottages and semi-cottages are made in the proportion of 300 per thousand, piccolos 699 per thousand, and cabinets only 1 per thousand. Now, taking this weekly produce as above stated, and assuming the prices to be the same as those given in the "London Journal," we thus arrive at the annual value of the piano-fortes manufactured in Great Britain.

Grands..........	25 × 52 = 1,300	at say £110	each	£143,000
Squares..........	20 × 52 = 1,040	,, 60	,,	62,400
Uprights........	1,450 × 52 = 75,400	,, 35	,,	2,639,000
Number of piano-fortes per annum..............	77,740	of the value of		£2,844,400

PICAMAR. See Tar.

PICROLITE. See Serpentine.

PICROTOXINE, the active principle of *cocculus indicus.* It forms small, colourless, stellated needles of an intensely bitter taste; soluble in 25 parts of boiling water, and in 3 of boiling alcohol. It is said to contain $C_{12}H_7O_5$.

PIER, from the French *pierre*, stone, a term applied to the pillar-like masses of masonry or brickwork from which arches spring, rising from what is termed the *impost* capping of the pier, which usually consists of a series of mouldings. See Bridge, sec. III.

PIETRA DURA. A term applied to the black marble used for inlaid works.

PILE-ENGINE. See Bridge, sec. III.—Steam.

PIN. The manufacture of pins furnishes employment to a large number of persons; for according to the ordinary mode of making them, each pin passes through fourteen pairs of hands before it is ready for use, without taking into account its previous preparation as mere wire. The pin-maker receives this wire in a very soft state, and covered with a scurf or oxidation from the annealing process. To make it clean, hard, and of the fineness required, it is pickled in dilute sulphuric acid, washed, beaten, and dried, and finally wound on a reel or barrel. The loose end is then filed, passed through a draw-plate, and attached to an iron barrel, which is turned by a horizontal handle. By this drawing process the wire is reduced in size and rendered hard and bright. It is next pulled from the barrel through another draw-plate to straighten it, and is then run out upon a low wooden bench or trough twenty feet long, which serves as the measure of the lengths into which the wire is cut. These lengths of 20 feet are next cut with shears worked by the foot into shorter lengths, each about sufficient for 6 pins. The pin-wires thus obtained are pointed at each end at a machine called a *mill*, consisting of a circular single-cut file, and a fine grit-stone. The pin-wires are applied 50 or 80 at a time, first to the file which points them, and then to the stone which polishes them, the grinder meanwhile spreading them out, and giving them a rotatory motion by the action

of the thumb and fingers. This employment was formerly exceeding injurious, but has been rendered less so by efficient factory ventilation. Without due precautions the fine particles of brass are inhaled and produce consumption, or enter the eyes and induce blindness. One pin is next cut from each end of the wire thus pointed, the intermediate piece being again delivered to the grinder to have its blunt ends pointed. Two more pins are then cut off, leaving the middle piece again to be pointed at each end. This middle piece is now divided in the centre, making the third pair of pins obtained from one wire.

Meanwhile the preparation of the pin-heads has been going on under the hands of another set of work-people. The wire for this purpose is much finer and softer than that for pins, and it is prepared by winding it in a close coil round a *mould* or wire 40 inches long, of the thickness of the pin. This coiling is effected by means of a small lathe, or Jersey spinning-wheel, to the spindle of which the mould is fastened. The heading wire is fastened to the end of the spindle, and passed, together with the mould, through two small loops in a wooden handle, which the workwoman holds in her left hand to regulate the winding, while her right turns the wheel. In this way a rotatory motion is communicated from the spindle to the mould wire; and the heading-wire being held at right angles to it, is closely coiled round it nearly from end to end, and is afterwards slipped off to make room for another. The disengaged coil is next cut up into heads, from two to two and a half turns of the spiral being the quantity required for each head. The cutting of the heads is effected by a sort of guillotine, the action of which is as follows:—A sharp chisel fixed vertically in a wooden frame is held down by a spring: a lever, proceeding from the upper part of the chisel, becomes engaged for a moment in one of the cogs of a wheel rotating near it: this depresses the lever and raises the chisel: then the lever, immediately escaping from the cog, the spring forces the chisel down; but no sooner is the chisel forced down than another cog comes into action, depresses the lever and raises the chisel: in this way the wheel, being furnished with a number of cogs, gives to the chisel a rapid chopping motion. Under the edge of this chisel the spirals, placed on a horizontal board, are gradually advanced, in so regular a manner that two turns of each spiral are cut off at each descent of the chisel.

The next operation is *heading* the pins, and for this purpose a boy takes a number of heads in his apron, and taking up a few headless pins in his fingers, he plunges them into his lap and works them about among the heads with a sort of threading motion. Most of the wires in this way catch up a head, some two or three heads, which superfluous ones are rapidly removed, and they are now ready for *moulding* or fixing securely the heads to the shanks. To effect this a man presses his foot upon a treadle, which, acting upon a lever, raises a weighted square bar of iron; he then places the pins point downwards, and one at a time, in a steel die, and suddenly removing his foot from the treadle, the bar descends, strikes the top of the pin, and at once shapes and fastens it. A small spring below the die prevents the pin from passing deeper into the die than two-thirds of its length, except when the heavy hammer descends and drives it home; as soon, therefore, as the blow is struck, and the man again presses the treadle, this little spring comes into operation, and raises the pin one-third out of the die, so that he can instantly remove it and insert another pin. An expert workman will fasten the heads of fifteen hundred pins per hour.

As far as the process of making the pin is concerned the work is now complete, but there remain several other operations to fit the article for use, and make it bright and clean. Pins are cleaned by boiling for half-an-hour in sour beer, wine lees, or a solution of tartar; after which they are washed. They are then whitened or tinned, by being laid in strata, in a copper pan, alternately with grain tin in the proportions of about six pounds of tin to seven or eight pounds of pins, until the vessel is filled. Water is then added, and heat applied; as soon as the water gets hot its surface is sprinkled with four ounces of cream of tartar, after which it is allowed to boil for an hour. This operation is repeated once or twice, the pins being washed in cold water between each boiling. After tinning, the pins are polished by agitation in a leather sack filled with bran, and after the bran has been separated by winnowing, the pins are collected in bowls for papering.

Crimping-irons are used to fold the papers which are to be filled with pins. Two of the folds are gathered together and placed with a small portion projecting between the jaws of a vice, which close with a slight spring, and which have grooves channelled in them to serve as a guide to the paperer, generally a girl, who sits before the vice with her lap full of pins. Passing a comb into the heap, she catches up a number of pins, the heads of which rest between the teeth of the comb. She takes them up and quickly runs them into the folds of the paper, regularity in so doing being preserved by the channels in the vice along which she drives the points of the pins. As soon as one row is complete she puts two more folds in the vice. Occasionally she drives the pin with too much force against the vice and bends it, when it is immediately taken out and thrown aside among the waste, which in this manufacture is reckoned at one-thirteenth of the total number of pins fabricated.

The above processes have been accomplished chiefly or entirely by machinery, and great fame was acquired by what were called solid-headed pins, where the head was not separate, but was raised from the wire itself by strong mechanical compression. A chief objection to these pins arose from the necessity of their being made of a softer wire than others, and therefore being very liable to bend. One of the most complete of the pin-making machines was that patented by Wright, in 1844. In this machine, "the rotation of a principal shaft, mounted with several cams, gives

motion to various slides, levers, and wheels, which work the different parts. A slider pushes pincers forward, which draw wire from a wheel at every rotation of the shaft, and advance such a length of wire as will produce one pin. A die cuts off the said length of wire by the descent of its upper chap; the chap then opens a carrier, which takes the pin to the pointing apparatus. Here it is received by a holder, which turns round, while a bevel-edged file-wheel rapidly revolves, and tapers the end of the wire to a point. The pin is now conducted by a second carrier to a finer file-wheel, in order to finish the point by a second grinding. A third carrier then transfers the pin to the first heading-die, and by the advance of a steel punch the end of the pin-wire is forced into a recess, whereby the head is partially swelled out. A fourth carrier removes the pin to a second die, where the heading is perfected. When the heading-bar retires, a forked lever draws the finished pin from the die, and drops it into a receptacle below."

The consumption of pins for this country only, is calculated at fifteen millions *daily*.

PINCHBECK. See BRASS.

PINE. See WOOD.

PINT, the half of a quart, and the eighth part of a gallon.

PIPE. According to the old wine measure, 2 hogsheads made a *pipe;* but 2 hogsheads of ale or beer made a *butt*.

PIPE. A channel for the conveyance of water, gas, &c. See CASTING and FOUNDING—GAS—LEAD—POTTERY and PORCELAIN, &c. A method of forming stone pipes is described under MARBLE, Fig. 1395.

PIPE-CLAY. See CLAY.

PISÉ-WORK. A method of constructing very durable walls of kneaded earth. It was probably suggested by the building processes of the ants: Pliny names these walls *formacie,* and the method of constructing them was well known to the ancients. Any kind of earth that will sustain itself with a small slope, is adapted to the purpose; but that best suited to it is clay, containing small gravel of sufficient consistence to be dug with a spade. It is first well beaten, then screened to separate stones larger than a common hazel nut; after which, it is wetted sufficiently to enable it to retain the form given to it by kneading between the fingers. It is now fit for use, and in applying it to build a wall, a sort of moveable

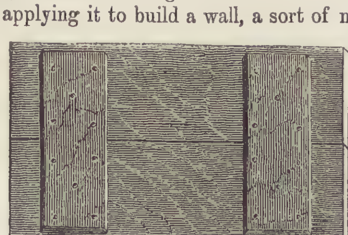


Fig. 1637.

box or mould is made for the intended wall of deal planks put together with their joints ploughed, and tongued, and strengthened with clamps on the outside. These frames, one of which is shown detached in Fig. 1637, are made 10 feet in length and 3 feet high; they rest on cross pieces or putlocks, which pass through the thickness of the wall, and near the ends are mortices, into which are placed upright pieces, 5 feet long, secured by wedges at the bottom, and tied with ropes *r*, Fig. 1640, at the top. A cross piece, an upright, and a wedge are also shown separately in Fig. 1638. These uprights are set to the intended thickness of the wall, which is about 20 inches at bottom, and gradually diminishes upwards. The frames are steadied at the top by means of cross sticks or struts *s*, Fig. 1640, and the ropes are made tight by twisting them with a small piece of wood placed between the folds. The frames being properly fixed, the earth is thrown in, and worked like concrete or mortar; to allow the putlocks to be readily withdrawn, the parts about them must be well wetted. In commencing a wall, the first frame is put at one of the extremities, and the end of the frame closed by planks secured by iron cramps, as shown in Fig. 1639;

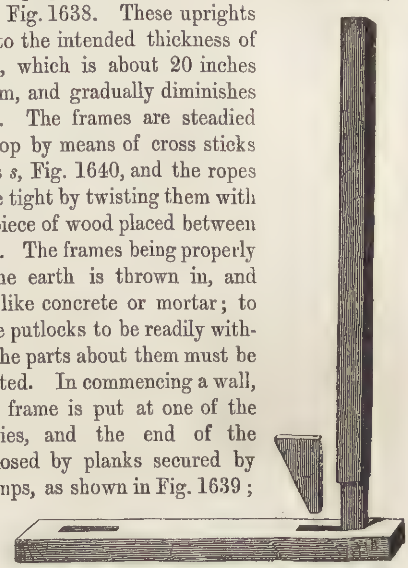


Fig. 1638.

at the other part, where there is no end, the wall is to be sloped off at an angle of about 60°, for facility in joining on the next piece. In commencing the work, the bottom being well cleaned and sprinkled

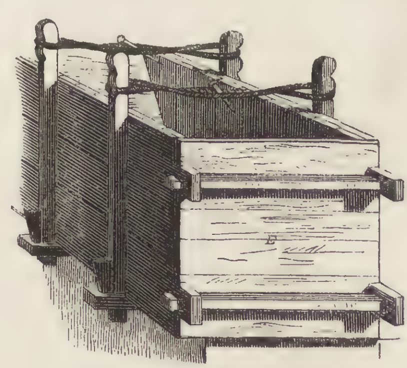


Fig. 1639.

with water, the labourers bring the masons the prepared earth in wicker baskets, of the form shown at *b* Fig. 1640, and tread it with their feet into a bed 3 or 4 inches thick; they then ram it down with a rammer, *r*, Fig. 1640, consisting of a block of ash, elm, or hazel, 10 inches high: square at the middle of its height, 6 inches by 5, diminishing in thickness, and terminated by rounded edges at the bottom: towards the upper part it is terminated by a circular surface, 4 inches in diameter, in the centre of which is a hole for the handle, which is 4 feet 2 inches long.

In ramming, it is turned round at each stroke, so as to make the work more compact, and unite it with that previously done. By means of the rammer, the first layer is reduced in thickness about one half, and on this compressed bed another layer is spread out, and beaten in the same manner, and so on, until the case is filled. The frame is then taken down and moved further on, so that the plank entirely covers the inclined part. Lintels are placed over all the apertures, and the finished portions are left for some months to dry. The surface may then be coated with plaster, and the wall is finished.

Fig. 1640 will show the method of building a wall in pisé, and the arrangement of the frames F F, the mode of securing them by the uprights U U passed into the putlocks P P, and secured by the wedges *w w*. The mode of terminating the piece of wall in progress by means of an incline is also shown; and in the opposite wall the junction of two pieces is shown by the diagonal lines. The small open square holes mark the places occupied by the putlocks, which were withdrawn on raising the frame a course higher. It will be seen that the first few courses of the wall are of masonry. This is for the purpose of keeping the foot of the wall out of the wet.

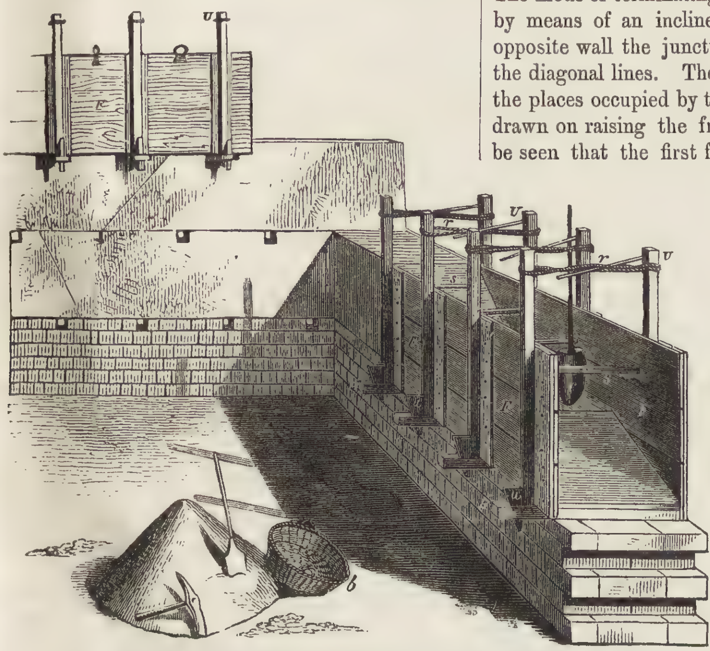


Fig. 1640. PROCESS OF BUILDING A WALL IN PISÉ.

Fig. 1641 shows a house nearly finished. This kind of work is very durable; and as an illustration thereof, Rondelet states, that in 1764 he repaired a chateau in the department of Ain, which was at least 150 years old, and that the walls had acquired a hardness and compactness equal to ordinary stone; so that in enlarging the windows and other apertures, the men used the same tools as in a quarry.

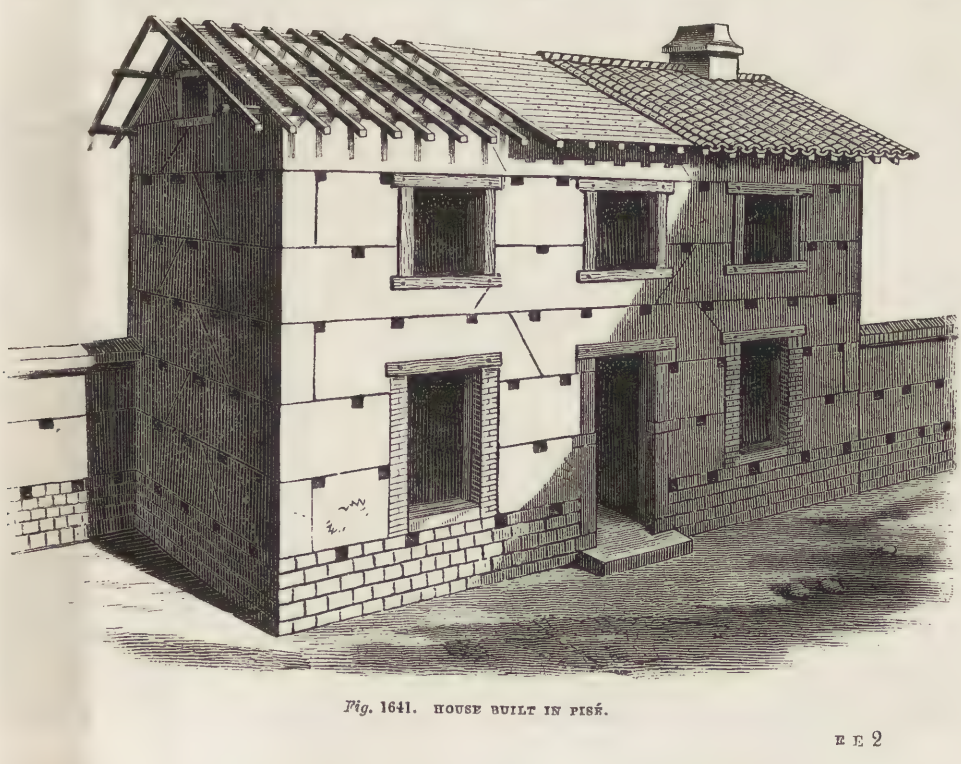


Fig. 1641. HOUSE BUILT IN PISÉ.

Cob walls, as they are termed in Devonshire, resemble pisé-work: they are formed of clay, loam, and chopped straw, and are generally 2 feet thick, resting on brick or stone foundations, 3 or 4 feet above the level of the soil; they must be carried up at several times, and not be hurried. After each addition, the sides are carefully pared down with an iron cob parer, which resembles a baker's peel. When dry, it is coated with fine stucco or plaster, and if kept dry at its top and foundation, it is very durable. It is usually tiled or thatched at top.

PISTOL. See Gun.

PISTON. See Pump—Steam, &c.

PIT-CRANE. A term sometimes applied to the common wharf crane. See Crane, Fig. 679.

PITCH. See Tar.

PITCHSTONE. A volcanic product, resembling Obsidian, but less perfectly glassy; it has a pitch-like lustre.

PITTACAL. See Tar.

PLANE. The plane used in carpentry is a chisel set in a stock or guide, for the purpose of regulating the depth to which it penetrates the wood, so as to enable it to cut instead of split the wood, and also for furnishing a well defined guide to the path or direction of the cutting edge. The sole or stock of the plane is usually an accurate counterpart of the form which it is intended to produce, and as in the majority of instances this is flat or plane, the instrument derives its name from this form. The sections of planes may, however, be concave, convex, or mixed, as well as straight, whence arise those numerous varieties known as *grooving* planes and *moulding* planes. Planes used for flat surfaces are termed by the joiners *bench* planes, or *surfacing* planes. These are all similar as it regards the arrangement of the chisel, or *iron* as it is termed, but the size may vary. In ordinary bench planes the width of the iron ranges from about 2 to $2\frac{1}{2}$ inches. The names and dimensions of surfacing planes are given in the following table:—

	Length in Inches.	Width in Inches.	Width of Irons.
Modelling planes, similar to smoothing planes	1 to 5	$\frac{1}{4}$ to 2	$\frac{3}{16}$ to $1\frac{1}{2}$
Ordinary smoothing planes ...	$6\frac{1}{2}$ to 8	$2\frac{3}{8}$ to $3\frac{1}{8}$	$1\frac{3}{4}$ to $2\frac{3}{8}$
Rebate planes	$9\frac{1}{2}$	$\frac{3}{8}$ to 2	$\frac{3}{8}$ to 2
Jack planes..........................	12 to 17	$2\frac{1}{2}$ to 3	2 to $2\frac{1}{4}$
Panel planes	$14\frac{1}{2}$	$3\frac{1}{2}$	$2\frac{1}{2}$
Trying planes	20 to 22	$3\frac{1}{4}$ to $3\frac{3}{8}$	$2\frac{3}{8}$ to $2\frac{1}{2}$
Long planes	24 to 26	$3\frac{5}{8}$	$2\frac{5}{8}$
Jointer planes	28 to 30	$3\frac{3}{4}$	$2\frac{3}{4}$
Cooper's Jointer planes	60 to 72	5 to $5\frac{1}{4}$	$3\frac{1}{2}$ to $3\frac{3}{4}$

Of these planes, those most commonly used are the jack-plane for the coarser work, the trying-plane for giving the work a better figure, or trying its straightness and accuracy, and the smoothing-plane for finishing the surface. When the wood is very rough and dirty, two jack-planes may be used.

The different parts of the ordinary surfacing-plane will be understood by referring to Fig. 1642, in which the line $s\,s'$ is the *sole; m b*, the line on which the plane-iron is supported, the *bed*, and this in planes of common pitch is usually at an angle of 45° with the perpendicular. The narrow opening between the face of the iron and the line $m\,w'$ is termed the *mouth* of the plane; the line $m\,w'$ is called the *wear:* the angle between the mouth and the wear should be as small as

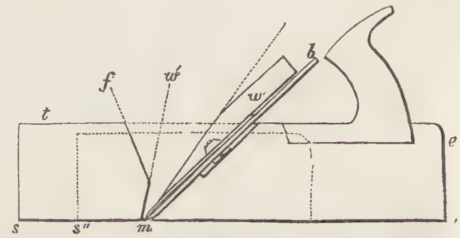


Fig. 1642.

possible, so that as the sole wears away, or is corrected, the mouth may not be too much enlarged; this angle must, however, be large enough to allow the shavings to escape freely, otherwise the plane will *choke.* The line f is the *front*, and its angle is usually set out $\frac{1}{4}$ of an inch wider on the upper surface than the width of the iron. The iron is fixed in its place by a wedge w, by slightly driving it between the face of the iron and the shoulder $m\,n$. The wedge, shown separately in Fig. 1643, is cut away at the central part, to clear the screw which connects the two parts of the iron, and to allow space for the shavings to escape. The wedge is loosened by tapping the end at e, or the top at t, or by tapping the side of the wedge itself; it may then be pulled out. A blow on the front of the plane at f sets the iron forward or deeper. The iron is somewhat narrower than the stock, and the mouth is a wedge-shaped cavity. When the stock terminates at the dotted line $s''\,s''$, it represents the *smoothing*-plane; when of the full length with the handle or *toat*, it is the *jack*-plane or *panel*-plane. The sole of the plane rests upon the face of the work, and the cutter stands as much in advance of the sole as the thickness of the shaving, which is so bent as to allow it to creep through the mouth up the face of the inclined iron. Considerable advantage is gained in having a double iron as in Fig. 1644, the top iron not being intended to cut, but to present a more nearly perpendicular wall for the ascent of the shavings, and as this iron more effectually breaks the shavings it is termed the *break*-iron. The lower

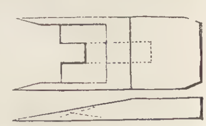


Fig. 1643.

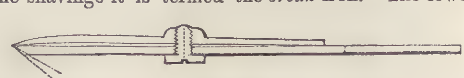


Fig. 1644.

piece is the one that cuts; the upper piece or top iron has a moderately sharp edge; it is placed from $\frac{1}{16}$th to $\frac{1}{50}$th of an inch from the edge of the cutter, and the two are held closely together by a screw passing through a long mortice in the cutter, and fitting into a tapped hole in the top iron. By the addition of the top iron the plane works more smoothly, but harder, and the more so the closer it is down, showing that its action is to break or bend the fibres: the shaving, being very thin, is constrained between the

two approximate edges, and as it were bent out of the way to make room for the cutting edge, so that the shaving is removed by absolute cutting, not by being split or rent off.

The angle at which the plane-iron is inserted in the stock depends upon the use to which it is applied. The spoke shave is the lowest of the series, its inclination being from 25° to 30°. In bench planes, for deal and similar soft woods, it is 45° from the horizontal line; this is called the *common pitch.* In bench planes for mahogany, wainscot, and hard or stringy woods, the *York pitch,* or 50°, is used. In moulding-planes for deal and smoothing-planes for mahogany and similar woods, the *middle pitch,* or 55°, is used. In moulding-planes for mahogany and woods difficult to work, (of which bird's-eye maple is said to be one of the worst,) *half pitch,* or 60° is adopted. Close hard woods, such as box, may be scraped smooth in any direction of the grain with a cutter placed perpendicular, or even inclined slightly forward. A tool with the cutter so arranged is called a *scraping-plane,* and is used for scraping the ivory keys of pianofortes, and works inlaid with ivory brass, and hard woods. In the process of veneering, use is made of a scraping-plane, with a perpendicular iron grooved into a series of teeth instead of a continuous edge, for roughing or scratching veneers, and the surfaces to which they are attached by means of glue. In the smith's plane for brass, iron, and steel, the cutter is vertical.

Planes work smoothly with the grain of the wood, which must always be considered in the operation of planing. Some of the ornamental woods however owe their beauty to the extreme irregularity with which their fibres are arranged, and in certain directions the fibres are liable to be torn up by the plane. By applying the smoothing-plane at various angles across the different parts of the surface, the desired effect may be attained; but with some curly, knotty, and cross-grained woods, the *steel scraper* must be used instead of the plane. The steel scraper (which had its origin in a piece of broken window-glass, still used by some of the gun-stock makers) is made of a thin piece of saw-plate; the edge is first sharpened at right angles upon the oil-stone, and is then burnished square or at a small angle, so as to throw up a trifling burr or wire edge. The scraper is held on the wood at about 60°.

Hard woods admit of being planed across the grain, both with flat and moulding-planes. With deal and other soft woods if a cutting edge be applied to the fibres, parallel with themselves, or laterally, they are liable to be torn up and present a rough unfinished surface. A keen plane of low pitch is therefore used for such woods, and it is made to slide obliquely across the wood, so as to attack the fibres from the ends. Moulding-planes do not admit of this application; mouldings in soft woods are planed lengthways of the grain, and added as separate pieces: but as rebates and grooves are frequently required to be made across the grain, the obliquity is then given to the iron, which is inserted at an angle, as in the *skew-rebate* and *fillister,* and the stock of the plane is arranged in various ways to guide the iron. Fig. 1645 is the back view, and Fig. 1646 the side of a side-fillister, for planing both with and across the grain; as

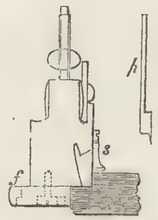


Fig. 1645.

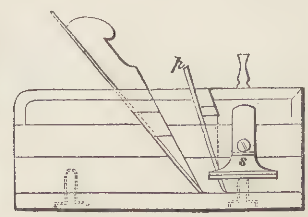


Fig. 1646.

in planing a rebate round the margin of a panel. The loose slip or fence *f* is adjusted to expose so much of the oblique iron as the width of the rebate; the screw-stop *s,* at the side, is raised above the sole of the plane, to suit the depth of the rebate, and the small tooth or scoring-point *p,* shown separately at *p,* Fig. 1645, precedes the bevelled iron, and divides the fibres so as to make the perpendicular edge true and square. The *plough* is also a grooving plane, in which the fence is secured to two transverse stems, passing through mortices in the body of the plane, and fixed by wedges. *Slit deal planes* belong to this class, as in Figs. 1647, 1648, of which the one makes the groove, and the other the tongue, used for connecting boards for partitions, &c., with the *groove and tongue joint,* Fig. 1649. There are many other forms of plane adapted to special uses, an account of which, including *moulding-planes,* is given in the admirable chapters on "cutting tools, chisels, and planes," in the second volume of Holtzapffel's "Mechanical Manipulation," to which we are indebted for many of the details in this article.

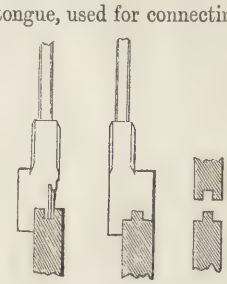


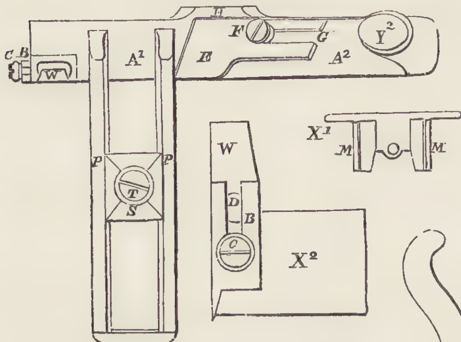
Fig. 1647. *Fig.* 1648. *Fig.* 1649.

We are anxious to devote a portion of our space to a notice of a remarkable form of plane patented in 1844, by Messrs. Silcock and Lowe, of Birmingham, which has met with approval from practical men. It is a *double fillister plane,* so constructed as to be capable of filleting boards of all sizes, from about $\frac{3}{8}$ ths of an inch to about 3 inches, and may be adapted to the several purposes of a *filleting plane,* a *side fillister,* a *sash* or *back fillister* and a *skewed rabbet plane.*

Fig. 1650 is a top view of the right side plane of this double fillister, and Fig. 1652 a similar view of the left side plane: Fig. 1651 is a side elevation of Fig. 1650, and Fig. 1653 a side elevation of Fig. 1652. These 2 planes, when joined together by the chase or frame P, form the complete tool. A^1 A^1 are the fore-parts of the body of each plane, and A^2 A^2 the back parts. H H are the pieces which connect the front and back parts; Y^1 Y^1 are the stocks, and Y^2 Y^2 the handles. B B are the vertical cutters attached to the front ends of the planes. X^2 is a front view of one of

these cutters It is fixed in its place partly by a screw C passed through a cleft in the upper end of the cutter, into the fore-end of the body of the plane, and partly by a pin D, which projects from the fore-end, and fits

Fig. 1650.



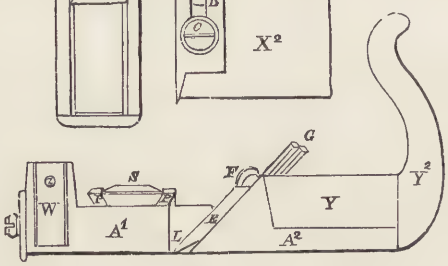


Fig. 1651.

into the cleft, the object of the pin D being to keep the cutter perpendicular to the side of the plane, and to prevent its being driven aside when in use. E E are the horizontal cutters or *irons,* which are not secured to their beds by wedges, but by screws, F F, passed into the stock through clefts G G in the top-ends of the irons. L is the mouth of the plane; P is a chase or frame projecting from, and attached at the

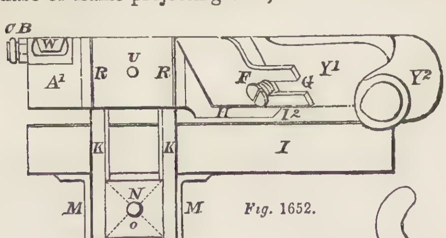


Fig. 1652.

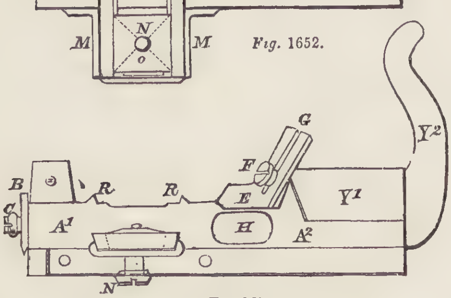


Fig. 1653.

inner end to the top of the forepart A^1 of the body of the right-hand plane, and slides into a recess R R on the top of the forepart A^1 of the body of the left-hand plane, the outer edges of the chase P being bevelled inwards, and the inner edges of the recess R bevelled outwards.

The length to which this chase P is slid into the recess R regulates the distance between the two planes, and this may be varied to suit boards of all sizes between the limits already mentioned. The planes are fixed at the required distance from each other by means of a traversing small screw T attached to the chase P, and in the recess R is a corresponding hollow screw U: the screw T has a sliding cushion S, by which it can be moved to and fro to any part of the frame P, and the sides of the cushions are bevelled to correspond with the bevelled inner edges of the chase P. I is a fence, by which the distance between the check or fillet and the front of the deal is regulated. L^2 is the inner-edge plate of the fence. K is a chase or frame, similar to P, and projects from, and is attached at the inner end to the bottom of the fore-part of the left-hand plane, and M (shown separately at X^1 Fig. 1650) is a third chase, which projects from, and is attached to, the outer edge of the fence I. The chase M, sliding within the chase K, and the 2 chases having for this purpose corresponding bevels at the parts where they come in contact, the lower chase M carries a fixed screw N, and the upper one a sliding nut O, similar to the sliding cushion S, so that when the fence has been adjusted to any required position, it is secured by bringing the nut O over the screw N and screwing up the one into the other. To regulate the height to be given to the fillet, a stop, shown in side and top views, Figs. 1654, and 1655, is used. The stem V of this stop fits into a recess W in the fore-end of the body of the plane, and by passing a screw X through a slot in the stem V and the hole Z, the stop is fixed at any required degree of

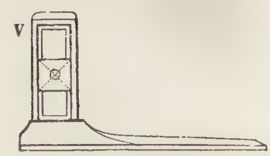


Fig. 1654.

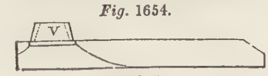


Fig. 1655.

elevation, and the depth of the cut thus determined. When this tool is used as a filleting plane both the right and left-side planes are employed, fixed at a distance from each other corresponding to the breadth of the fillet. To use it as a side fillister, the left-side plane, Figs. 1652 and 1653, is alone used, with the stop inserted into the recess W. When used as a sash or back fillister, the right-side plane, Figs. 1650 and 1651, is used, but with a slight modification in the figure of the fence represented in the side and top views, Figs. 1656 and 1657. To use the tool as a skewed rabbet plane, the right-hand plane, with its chase P and the fence F, are laid aside, and the left-hand plane only employed. In this plane, the stock, the handle, and body of the fence, are of wood: the

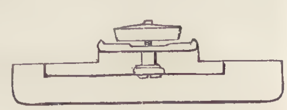


Fig. 1656.

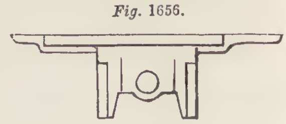


Fig. 1657.

screws F F, the cushion of the travelling-screw T, and the sliding nut O, are all of brass. All the other parts are of cast-iron, protected from corrosion by tinning or zincing. The fore and back parts, A^1 and A^2, are cast in one piece. The wood of the handle is not cut across the grain as usual, but with the fibres running

in a direction at right angles with the body of the plane, whereby a considerable increase of strength is gained.

This patent also includes a *dado-grooving plane*, with which upwards of sixteen different sizes of work may be

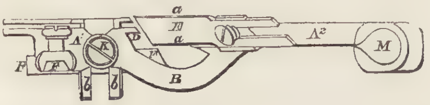


Fig. 1658.

executed. Fig. 1658 is an elevation, and Fig. 1659 a plan of this tool. A A^2 are the front and back parts of the body of the plane, which are connected together by the bow-piece B: D is a plate, cast in the same piece with the body, the lower edge of which forms the sole, and is about $\frac{1}{8}$th inch thick. E is the plane-

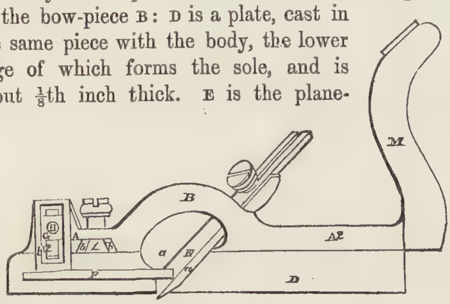


Fig. 1659.

iron, which is made at the upper end, and secured in its seat both in the same way as the irons of the double-fillister plane, and terminates at the cutting edge in two projecting edges *a a*, which, when the iron is ground and set up, act as side-cutters. A $\frac{3}{4}$ inch iron, adapted to this plane, is shown in Fig. 1660, but the size may vary from $\frac{1}{8}$th inch to $\frac{1}{4}$ inch. F is a stop fence for regulating the depth of the groove: it is fixed and shifted by means of an upright arm F^2, which slides in a groove in a projecting part of the fore-body of the plane, and a traversing nut and screw G H. I is a side fence, the under edge of which is all but flush with the sole of the plane: it has 2 bevel-edged prongs *b b*, which pass through a slot in the body of the plane, and by means of a traversing nut L, inserted between these prongs and a screw-pin K, the fence is fixed in its proper working position, which is when it is in a right line with the outer edge of the cutting-iron Fig. 1660. M, the handle, is the only part of this tool which is of wood. The materials and mode of putting together are the same as in the double fillister-plane.

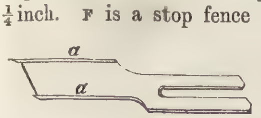


Fig. 1660.

This patent also includes a *fluting* or *grooving-plough*, a *trying plane*, adapted for both rough and fine work, and a *moulding* or *bead-plane*.[1]

The amount of time and labour required for planing by hand has led to the introduction of PLANING MACHINES. The first machine of this kind of which we have any distinct notice, was patented by General Bentham in 1791.[2] It was based upon the action of the ordinary plane, but was not much used. It appears, however, to have suggested the *scale-board* or *scabbard-plane*, for cutting off the wide chips used for making hat-boxes. The *scale-board machine* used by Messrs. Esdaile and Margrave at the City Saw-mills, London, has a wide cast-iron slide plate, working freely in chamfer bars raised on frame-work about 6 feet from the ground. Steam-power is applied to the slide by means of a strap or 2 straps for the to-and-fro motion. The slide is perforated for a cutter upwards of 1 foot wide, placed beneath the slide, and inclined horizontally about 40°, but the pitch of the iron, or its vertical face, up which the shavings slide, has an inclination of only 20°. The log of wood is used wet, on account of its increased elasticity in that condition: it is held down by weights, while the metallic plane slides beneath it, and shaves off one clean shaving or scale, the thickness of which is determined by the adjustment of the cutter.

Mr. Bramah, in 1802, took out a patent for a planing-machine, in which the timber was passed under a large horizontal wheel driven by steam-power at the rate of 90 revolutions per minute. The face of the wheel was armed with 28 gouges, placed horizontally and in succession around it, the first gouge being a little more distant from the centre and a little more elevated than the second, and so on. The finishing tools were 2 double irons.[3]

In Mr. Morris's patent planing-machine for flooring-boards, a rotatory adze roughly planes the bottom and another acts on the top of the board: two oblique fixed cutters next remove each a shaving of the full length and width of the deal: two cutters make the sides parallel, and 2 other grooves form the edges for the tongues. The board enters the machine as it comes from the saw-mill: it is driven forward by the engine, and soon comes out in a condition fit for fixing, or nearly so, for it may sometimes require a little finishing with the hand smoothing plane in parts where the grain is unfavourable to smooth cutting.[4]

Cutters with circular motion for producing mouldings and other works usually executed with hand-planes are liable to some objections; there is a difficulty in constructing and in sharpening them, and although driven with great rapidity they leave marks upon the work, because there is a distinct, though small, interval of time between the passage of one

(1) A description of these, with illustrations, will be found in the *Mechanic's Magazine*, No. 1096. It may be interesting to state that the cabinet-makers of Birmingham, at one of their monthly meetings, passed a resolution approving of Messrs. Silcock and Lowe's planes, "as a great improvement and advantage, and recommend them to the trade as very useful and cheap articles."

(2) See INTRODUCTORY ESSAY, page cxli.

(3) This machine is fully described in Nicholson's "Architectural Dictionary." A remarkable feature in this machine was the arrangement of the axis of the cutter-wheel. The bottom of this axis was cylindrical to the extent of its vertical adjustment, and was fitted in a tube terminating in its upper part in a cupped leather collar, impervious to oil or water, as in the hydrostatic press. The injection of water into the tube by a small force-pump lengthened the column of fluid, on which the wheel was supported as on a solid post. By allowing a portion of the water to escape by a valve, the descent of the wheel was readily effected.

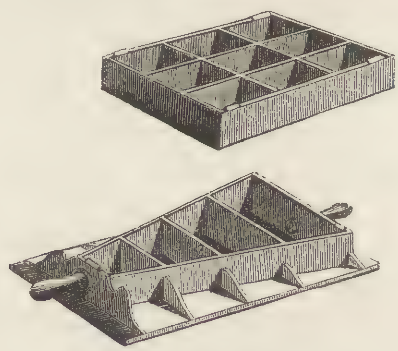
(4) The cutting and moulding machines for wood used in the erection of the Great Exhibition building are described in the INTRODUCTORY ESSAY, pp. xxxix to xlii.

cutting edge, and that next following; and during this interval, the advance of the work being uninterrupted, certain portions are less reduced than others, and small hills and ridges are produced above the general surface, which require to be smoothed off by hand. In Messrs. Burnett and Poyer's machine revolving cutters have been rejected, and fixed cutters employed. In planing mouldings they employ a stock containing from 12 to 20 cutters, each figured and secured by a separate wedge, so that the first cutter penetrates but little into the moulding, and each succeeding tool removes its own shaving; all the cutters gradually assimilating more and more to the last of the series, which is sharpened to the exact form of the moulding. With such a machine, mouldings in pine wood can be worked at the surprising rate of 70 lineal feet per minute, and the smoothness is equal to that produced by the joiner's hand planes in the usual manner.

PLANOMETER. A name given to the trial or surface plates by which certain flat parts in metallic works are tested. The surfaces by which the stationary parts of framings are attached must be tolerably true, or when screwed up they are liable to bend and distort the machine; but very exact and finished surfaces are required for the rectilinear slides and moving parts of accurate machines for the valves of steam engines, tables of printing presses, &c. The machinist does not always attain this degree of excellence; nevertheless for want of it there is great waste in time, in steam power, in wear and tear, and above all in skill misapplied.

For producing accurate work a true straight-edge, and a true surface plate are indispensible. The file and the scraper are the only instruments that should be allowed in producing a truly flat surface: grinding should be altogether excluded; since, in grinding two surfaces together, one is very apt to become convex and the other concave nearly to the same extent. There is also another objection to grinding; some of the grinding powder is always absorbed by the metal, and the metallic surfaces are thus converted into laps, to the mutual injury of the slides and works. Mr. Whitworth remarks that practically the excellence of a surface consists in the number and equal distribution of the bearing points; but that if a ground surface be carefully examined the bearing points will be generally found lying together in irregular masses with extensive cavities intervening. This arises from the unmanageable nature of the process. The action of the grinding powder being under no control, there are no means for securing its equal diffusion or for modifying its application with reference to the particular condition of different parts of the surface. The practical result of this is, that the mechanic neglects the proper use of the file, knowing that grinding will follow to efface all evidence either of care or neglect. If grinding be discontinued, machines will improve in accuracy: the surface plate and the scraping tool will then come into use, and a new field be opened to the skill of the mechanic. With a true surface plane he will, with a little practice, find no difficulty in bringing up his work to the required nicety.

The straight-edges used by smiths are usually of steel; the edges may be acute, but are commonly of some width, with a length of from 7 to 10 feet. The width of the edge may vary from $\frac{1}{16}$ to $\frac{1}{4}$ inch. Cast-iron straight-edges from 6 to 9 feet long, the width is 2 or 3 inches. In using the straight-edge for testing a surface which is being corrected, it is placed along the four margins of such surface, across its two diagonals, and at various intermediate parts; if the light cannot be seen between the edge and the surface in any of these lines the surface is correct. But this method alone is tedious, and not always sufficient where great accuracy is required; a true surface plane is therefore employed. It generally consists of a plate of hard cast-iron, with ribs at the back to prevent it from bending either from its own weight, or from taking an unequal bearing on the bench or other support. Mr. Whitworth recommends that the ribs be placed obliquely, and made to converge to 3 points of bearing as in Fig. 1662, so that the planometer may be supported on precisely the same points notwithstanding the inequality of the bench on which it rests; this can scarcely be the case when the planometer rests on 4 feet or prominent points at the corners as in Fig. 1661. The handles



Figs. 1661, 1662.

at the ends of Fig. 1662, are useful additions, allowing the planometer to be inverted and applied to heavy works which cannot be conveniently lifted.

Suppose it is required to produce a flat surface on a piece of cast-iron. It is first chipped all over with a chipping chisel and a hammer, in order to remove the sand of the foundry mould, and the hard superficial *skin* formed by contact with the moist sand. [See Casting and Founding, page 345.] The rough edges or ridges left by the chipping chisel are then levelled with a coarse hand-file, especially those parts which appear from the straight-edge to be too high. When the rough errors have thus been corrected, the work is removed from the vice, struck edgeways to shake off loose filings, and inverted on the planometer. But in order that this instrument may afford practical indications as to the parts of the work which first require correction, the planometer is coated all over with powdered red chalk mixed with oil, so that when the work is placed upon it, the prominent parts, or

those which require to be first removed, become coloured. On first trial the work may rest only on the two highest points; by a slight rubbing some other high points may pick up some of the colour. The work is then returned to the vice, and the file applied chiefly at and about the coloured parts, the straight-edge being occasionally used, and after some time the planometer is again resorted to. It is now probable that several points become coloured; these are in like manner rubbed down, and by carefully working in this way the number of points which are coloured on applying the work to the planometer become greatly increased. The smith's plane may be used in conjunction with the file, first with a grooved cutter, and then with a straight-edge. The planing and filing are alternated until patches of colour are taken up from the planometer; the scraper is then used to complete the work. The scraper may be made from a three-sided file carefully sharpened on a Turkey stone, the sharpening being frequently repeated. If these processes be conducted with care and judgment, and the work and the planometer wiped clean, and both be rubbed hard together, the high points of the work will be somewhat burnished, and produce a finely mottled appearance. The planometer should be evenly tinted with colour, and towards the conclusion the quantity of red should be only just sufficient to mark the summits of each little elevation.

Thus it will be seen that the production of a flat surface is a delicate operation, requiring care and watchfulness on the part of the engineer. Far more difficult is the originating the planometer itself, an interesting description of which operation is given in Holtzappfel's "Mechanical Manipulation," vol. ii.[1] At the meeting of the British Association held at Glasgow in 1840, Mr. Whitworth exhibited surface planes so true that when one was put upon the other it floated until by its weight it excluded some of the air, when the two adhered together with considerable force.

PLASTER OF PARIS. See GYPSUM.

PLASTERING is the art of applying adhesive plaster or cements to walls, ceilings, &c., for the purpose of concealing the roughness of brickwork or masonry, or the timber framing of partitions, floors, roofs, and staircases; and also for allowing the application of painting, paper-hanging, or other mode of decoration. It is also the business of the plasterer to form and fix ornamental cornices, centre pieces, and other similar ornaments. Plastering does not contribute to the stability of a structure, but adds greatly to its neatness, elegance, and comfort. Its general introduction is of comparatively recent date, for we still find in houses built only a century ago, wainscoted walls, and boarded, or boarded and canvassed ceilings, or joists entirely uncovered.

In applying plaster to a brick wall, the surface must be mode rough and prominent, in order that the plaster may adhere properly. In building a new wall which is to be plastered, the joints are left rough and prominent instead of being *drawn* with the trowel, as is done for exposed brickwork. In old walls, the mortar must be removed to a small depth, as for repointing, and the surface of the brickwork be roughened by *stabbing* or *picking* it over. The surface is then brushed free from dust, wetted with water, and the first coat of plaster applied in a fluid state, with a coarse bristle brush; before this is quite dry a coat of coarse plaster may be added. In plastering upon quarter partitions, or on the under surface of timber floors, an artificial surface is formed for the plaster by nailing narrow slips of wood, named *laths*, to the timber quarterings, or to the joists. Laths are usually of fir, about 1 inch in width, and from 3 to 5 feet in length, and they occur in three thicknesses, viz. $\frac{1}{4}$ of an inch, which is termed *single lath;* $\frac{3}{8}$ths of an inch, or *lath and a half;* and $\frac{1}{2}$ of an inch, or *double.* They are formed by splitting or *rending*, not only for economy of wood, but also for roughness of surface, and greater strength and elasticity. They are nailed with cast-iron nails,[2] transversely across the joists, with a narrow slit or opening between every two adjacent laths. It is sometimes necessary to level the under surface of the joists, by attaching slips of wood termed *furrings* or *firrings*, so that the laths may occupy one plane. The laths should also be of uniform thickness, and made to break joint as much as possible; but greater strength is gained by making the ends of the continuous laths meet upon a joist or quartering. The first coat of plaster is called *coarse stuff*, and is a mortar of lime and sand mixed with ox or horse hair, to give it consistency; this is applied with a trowel in such a way as to force the mortar into the narrow openings between the laths, behind which it sets or hardens, in the form of little swellings or lumps, and thus becomes *keyed*, or secured to the laths very firmly. If two coats only are to be applied to the laths, the plastering is termed *laid and set;* the first coat, or the laying, is levelled with the trowel, and when sufficiently dry, its surface is scratched up or roughed with a birch broom, and a thin coat or *set* of finer plaster is laid on and smoothed with the trowel, with occasional moistening with a bristle brush. The first coat may also require to be sprinkled to promote adhesion. In the better kind of work, where three coats are applied, the first is laid on roughly, and while soft is scored over with a pointed lath, with cross lines 3 or 4 inches apart, and as deep as they can be made without laying bare the laths. These lines enable the second coat to adhere more firmly. The first coat may project $\frac{1}{4}$ or $\frac{3}{8}$ths of an inch from the laths, and is then called *pricking-up*. When it is become firm by drying, ledges or margins of plaster 6 or 8 inches wide, termed *screeds*, are formed at the angles, and at intervals of a few feet across the surface, and are adjusted to nearly the degree of projection or level of the finished surface, so as to form guages for the rest of the work. The spaces or bays

(1) See also Smith's Panorama of Science and Art.

(2) Oak-laths are occasionally used, and they must be secured with wrought-iron nails.

between the screeds are filled up flush with them, and the plaster levelled by means of flat wooden *floats*, (made with one or two handles, those with two handles being termed *derbys*, or *derby-floats*,) and *straight-edges*, or long pieces of wood planed to a straight-edge. When the second coat is dry, it is swept over, and a third coat of *fine stuff*, or plaster made with very fine white lime, is applied and well floated until it forms a smooth hard surface. In applying plaster to a brick or stone wall the first rough coat is termed *rendering* instead of *laying*. Ceilings or fine surfaces that are to be whitened or coloured, are finished with a fine plaster, made of the best powdered lime, well worked with water into a paste or *putty*, as it is termed. For surfaces that are to be papered, a stuff a little less fine, mixed with a small proportion of hair, is used. Surfaces intended for painting, are finished or *set* with *bastard stucco*, consisting of two-thirds ordinary fine stuff without hair, and one-third very fine clean sand; the last coat is finished with the trowel without the float.

The plasterer is attended by a labourer to supply his boards with mortar, and a boy on the scaffold to feed his *hawk*. This is a piece of wood 10 inches square, held by a projecting handle at the bottom, and is adapted to the reception of a small quantity of mortar. The laying-on trowel is a thin plate of hardened iron or steel, 10 inches long, and 2½ wide, rounded at one end, and square at the other end or heel. It is very slightly convex on the face. About the middle of the back the spindle or handle is riveted in at right angles, and this returning in the direction of the heel, parallel to the tool, fits into a rounded wooden handle, by which the workman grasps it. When not in use, this tool must be kept perfectly clean and dry, for if a spot of rust were to form on it, it would stain some of the delicate plasters with which it is used.

The construction of cornices is also the work of the plasterer. Cornices may be plain or ornamented, or both. If they project more than 7 or 8 inches, *brackets* or pieces of wood must be fixed at distances of 11 or 12 inches all round the site of the intended cornice, and laths be nailed to them: the whole is then covered with a coat of plaster. A beech mould is made by the carpenter with the profile of the intended cornice: the mould is about ¼ inch thick with the *quirks* or small sinkings of brass. The plasterer must remove all sharp edges, and open with his knife the points which will not receive the plaster freely. The cornice is then run by 2 workmen, who are provided with a tub of putty and a supply of plaster-of-Paris. Before using the mould they gage a screed upon the wall and ceiling of putty and plaster, covering so much of each as will correspond with the top and bottom of the intended cornice. On this screed are nailed one or two slight deal straight-edges, adapted to as many notches or chases made in the mould for it to work upon. The putty is mixed with about one-third plaster-of-Paris, and brought to a semi-fluid state with water. With 2 or 3 trowelfulls of this composition upon his *hawk*, which he holds in his left hand, he begins with his trowel to plaster over the surface intended for the cornice, while his partner applies the mould to see where more or less is wanted. When a sufficient quantity of plaster has been laid on, the mould is held steadily and firmly to the ceiling and wall, and moved backwards and forwards, the effect of which is to remove the superfluous stuff and leave an exact impression of the mould upon the plaster. In the course of this operation the other workman fills up any deficiencies that may occur with fresh plaster. In this way the work is executed with rapidity; the plaster is sprinkled from time to time with water during the progress of the work, to prevent it from setting too quickly. To secure the correctness of the cornice it is desirable to finish all lengths or pieces between any two breaks or projections at one time. Cornices of large proportions may require 3 or 4 moulds. Internal and external mitres, and small returns or breaks, are modelled and filled up by hand at a subsequent operation. When cornices are to be charged with ornaments, certain projections are made in running the mould, so as to leave a groove or indentation in the cornice into which the ornament is laid, and secured in its place by plaster-of-Paris. These ornaments are cast in plaster-of-Paris from clay models, but of late years other substances, lighter and less liable to injury than plaster, have been used, such as *carver's compo*, consisting of a mixture of whiting, resin, and glue; *papier maché*, with a priming of whiting and glue over it, when sharp impressions are required; *carton pierre*, with layers of whiting and glue; and *gutta percha*. One of the advantages of carver's compo is, that not being brittle, ornaments can be bent about and adjusted while being fixed, or after they are fixed.

Plasterers' work is measured in feet and inches, and charged by the superficial yard of 9 square feet, according to its quality. Special charges are made for arrises or external angles, quirks, mouldings, and other enrichments and carved work.

Such are the details of the plasterer's art in England, where materials for lime are abundant, but where the means for making plaster, properly so called, are limited. In other words, this country possesses abundance of carbonate, but very little sulphate of lime; plenty of chalk and limestone, but not much gypsum. In the neighbourhood of Paris, on the contrary, where gypsum is abundant, and is extensively burnt into plaster-of-Paris,[1] the art of the plasterer varies with his material. The coarser kinds of plaster are used for ordinary work, such as walls and partitions; the finer kinds being used for ceilings,

(1) As the plaster is apt to become discoloured when the gypsum is burnt with ordinary fuel, an improved method of preparing the plaster has been suggested. It is founded on the fact, that high-pressure steam, like gases at a high temperature, greedily absorbs water from any bodies with which it may be in contact. A jet of steam raised to upwards of 400° Fahr., is projected upon the gypsum broken into small lumps, when it takes up all the water, and leaves the plaster in the state of a pure anhydrous sulphate of lime. The difficulty of the process consists in making the chamber and machinery strong enough to resist the action of the high-pressure steam without too great an outlay.

cornices, &c. For walls, the plaster must be gaged stiff for the first coats, and more fluid for the setting coat. For cornices worked out in the solid, the core is of stiffly-gaged plaster: this is floated with finer material and finished off with plaster of about the consistence of cream. Walls are first jointed and wetted with a broom: a coat of thinly-gaged stuff is laid on with a broom, or worked roughly with a trowel. The next coat is gaged stiff, laid on with a trowel, and floated with a rule, but the face is finished with a hand-trowel. The rapidity with which the plaster sets does not allow the surfaces to be so even, or the angles so sharp and true as with us. The rapid drying is however a great advantage. Walls of this kind are not capable of resisting the action of water.

Plaster has much less tenacity than mortar, the one decreasing, and the other increasing with time.

New walls, or walls in damp places, are apt to generate nitrate of potash, which works its way to the surface, where it effloresces and carries off the paint in large patches. The workmen call this the *saltpetre rot* or *saltpetering*. It is not, however, pure saltpetre, for nitrate of soda and chloride of potassium are also found with it. This effect, which is not easily explained, will be further noticed under POTASSIUM.

PLATE-GLASS. See GLASS, Sect. viii.

PLATING is the art of producing works in an inferior metal covered with a film of silver, so as to have the appearance of being made of the precious metal. The application of thin leaves of silver to finished brass articles appears to have been the original method of plating, and was long known as *French plating*. Articles in steel, such as dessert-knives, were also plated in this manner. A piece of silver leaf was placed on each side of the blade sufficient to cover it, and the knife was then introduced into a furnace until the union of the two metals was effected. The knife was then finished by burnishing. With brass goods the surface was made chemically clean, and the part to be plated was heated to a point just below that at which the metal changes colour; silver leaf was then laid on, and the adhesion produced by burnishing, a fine polish being produced by the latter process. It is worthy of remark, that the old method of coating articles made of an inferior metal with a superior metal, is now again adopted, under the guidance of the refined and elegant principles of electric science. See the section on ELECTRO-PLATING under the article ELECTRO-METALLURGY.

The goods produced by the old method were not found to be very permanent. A better plan was therefore resorted to, and which is still practised at Sheffield, Birmingham, and elsewhere. In this process the metal is first produced in sheets plated on one or both sides, and the goods are manufactured from these sheets. An ingot of alloy of copper and brass is cast about $1\frac{1}{8}$ inch thick, 3 inches broad, and 18 inches long. This ingot must be free from holes and flaws: it is cast in an iron mould furnished with rising mouth-pieces, to give a certain amount of pressure to the metal, and to allow impurities to rise above the general surface. The face of the ingot is carefully dressed with a file on one side for what is termed *single* plating, and on both sides for *double* plating. A thickness of silver is then laid upon the copper, equal in weight to about $\frac{1}{24}$th or $\frac{1}{30}$th of that of the copper, and for double plating about $\frac{1}{12}$th or $\frac{1}{15}$th; the proportional thickness of the two metals varying in the single plating from $\frac{1}{30}$th to $\frac{1}{40}$th. The plate of silver is cut rather smaller than the ingot, and is accurately tied to it with iron wire, after which a little saturated solution of borax is brushed in at the edges. The ingot is now ready for the plating furnace. This is heated with coke, put upon a grate at a level with the bottom of the door. The latter has a peep-hole in it, through which the workman watches the operation. The ingot is placed upon the coke; the water of the solution of borax speedily evaporates, and the borax itself fuses and excludes the air from under the silver, for this might oxidise the copper and prevent adhesion. The proper temperature of the ingot is indicated by the silver being drawn into contact with the copper, and the moment the man perceives this to have taken place he removes the bar from the furnace, for if left longer the silver would become alloyed with copper, and the plating be spoiled. The operation is complete when a film of silver solder is formed at the surfaces of contact.

The ingot is next cleaned, and then rolled out into sheets of the proper thinness between cylinders, with frequent annealing during the process. After the last annealing, the sheets are immersed in hot dilute sulphuric acid, and scoured with fine Calais sand: they are then ready to be formed into the large variety of articles which are produced by *raising* with the hammer; by *spinning* in the lathe; by *stamping*, *chasing*, &c.; and as these processes are adopted in fashioning any of the malleable metals, we must refer our notice of them to the article RAISED WORKS IN METAL.

The plated copper-wire used for making bread-baskets, toast-racks, snuffers, &c., is produced in the following manner. The silver is first formed into a tube, with one long edge projecting over the other, and a red-hot copper rod being inserted into this tube, the edges of the silver are made to unite by the pressure of a steel burnisher. The silver tube being thus completed, is cleaned inside, and put upon the copper rod which is to be covered, and which it exactly fits. This rod is somewhat longer than its silver coating, and being grooved at the extremities of the silver, the silver edges are worked into the grooves in order to exclude the air from the covered part. The rod is then heated to redness, and rubbed briskly over with the steel burnisher lengthways, so as to unite the two metals firmly into a solid rod, which is now ready for drawing into wire of the required form and fineness.

PLATINUM (Pt 99), the heaviest of all known substances, its specific gravity being about 21. This metal was not brought into Europe until the middle of the last century, although it had long been known in America under the name of *platina*, which signifies, in Spanish, *little silver;* but it was of very little value

on account of the great difficulty of working it. Platinum occurs in Brazil pure and native, mixed only with palladium. It also occurs in combination with a variety of substances, such as palladium, rhodium, iridium, osmium, ruthenium, iron, copper, and lead, and sometimes with silver;—mixed also with grains of osmium-iridium, gold, titaniferous iron, chrome-iron-ore, hyacinth, spinelle, and quartz; and with gold amalgam, which remains behind after the extraction of the gold by mercury. All these substances are found in different varieties of what is called *crude platinum-ore*, or *crude platina*, or *platiniferous sand.* The latter is found chiefly in rivers and alluvial deposits in various parts of South America; on the western declivity of the Ural Mountains in Russia; also in Borneo and other places. Indeed, it appears to be much more widely distributed than was formerly supposed. Crude platinum occurs in small flattened grains of a greyish-white colour, resembling tarnished steel: they vary in size from that of linseed to that of hempseed, but larger fragments have been discovered. The complicated nature of the ore renders the chemical treatment also complicated,[1] but the general process is as follows:—The crude metal is acted upon, as far as possible, by nitro-hydrochloric acid; a deep yellowish red and highly acid solution is produced, and to this is added sal-ammoniac, which throws down nearly the whole of the platinum in the state of ammonio-chloride. This is well washed with cold water, dried and heated gently in a black-lead crucible, just sufficient to expel the sal-ammoniac, so that the *spongy* platinum may be left in a loose state. It is gently rubbed to powder between the hands, pressed through a linen bag, and the coarser particles which remain in the bag are triturated in a wooden mortar with a wooden pestle. No harder substance must be used, or the powder will acquire metallic lustre, and the particles will not weld properly together. The powder is lastly triturated with water, and the finer particles are separated from the coarser by elutriation. The whole of the fine powder is then mixed up with water to a uniform paste, and pressed into a brass cylinder $6\frac{3}{4}$ inches high, 1·12 inch in diameter at top, and 1·23 at bottom: its lower and wider end is accurately closed with a steel stopper, which enters it to the depth of $\frac{1}{4}$ inch, and is wrapped round with bibulous paper, by which the running off of the water is facilitated. The interior of the cylinder is smeared with grease, and the cylinder being placed in a glassfull of water, is itself filled with water, and then completely filled with the platinum paste. In this manner all cavities and inequalities are avoided. On the platinum paste is laid, first, a piece of blotting-paper, then a layer of woollen cloth, and part of the water is pressed out of it by means of a wooden cylinder held in the hand. A plate of copper is then laid upon the paste, so that the cylinder may be introduced in a horizontal position into a very powerful lever-press, Fig. 1663. It consists of a flat iron bar, set edgeways, and screwed down by a hook E near its middle, where it would otherwise be liable to bend, to a strong wooden bench C D. The bar is connected by a pivot at its extremity A with the lever A F G. An iron rod, F H, which turns at its two extremities upon the pivots F and H, proceeds from the lever at F, and as the lever descends, propels forward the carriage I, which slides along the bar. A stopper or block being placed in the vacant space I *k*, the carriage communicates motion to the cradle *k l m*,

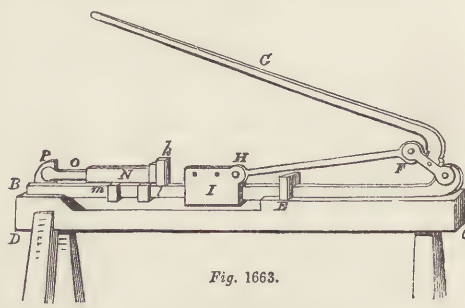


Fig. 1663.

which is also made to slide along the bar, and carries the barrel N, which lies upon the cradle, straightforward against the piston O, which rests by its end against P, a projection in the further extremity of the bar. After compression, which is to be carried as far as possible, the stopper at the extremity being taken out, the cake of platina will easily be removed on account of the conical form of the barrel. The cake is now hard enough to bear handling without breaking: it is placed upon a charcoal fire, and heated to redness, in order to drive off moisture, burn off grease, and promote cohesion. The cake is then heated in a wind furnace, for which purpose it is raised upon an earthen stand about $2\frac{1}{2}$ inches above the grate, the stand being covered with clean quartzose sand, on which the cake is placed on one end. It is then covered with an inverted cylindrical pot of the most refractory crucible ware, and the furnace is raised to its most intense heat, in order to drive off all impurities and prevent the platinum from blistering, which is its usual defect in its manufactured state. The furnace is fed with coke, and the action continued for about 20 minutes from the time of lighting it, a breathing heat being maintained for the last 4 or 5 minutes. The cake is then removed, placed upright on an anvil, and struck while hot on the top with a heavy hammer so as to close the metal. If the metal becomes bent in the hammering, it must not be hammered on the side, or it will crack: it must be straightened by blows on the extremities, directed so as to reduce to a straight line the parts which project. The ingot, thus formed, may now be forged into the required form like any other metal. After forging, it may be cleaned from ferruginous scales by smearing over it a moistened mixture of equal parts, by measure, of crystallized borax and salt of tartar; which, when in fusion, form a ready solvent for such impurities; and then exposing it on a platinum tray, under an inverted pot, to the heat of a wind furnace. The ingot, in

(1) The reader interested in the subject is referred to the translation of the sixth volume of Gmelin's "Hand-book of Chemistry," published in 1852 by the Cavendish Society, for the fullest notice of platinum that we are acquainted with.

being taken out of the furnace, is to be immediately plunged into dilute sulphuric acid, which in a few hours will entirely dissolve the flux adhering to the surface. The ingot may then be flattened into leaf, drawn into wire, or submitted to any of the processes of which the most ductile metals are capable. The sp. gr. of the metal thus prepared, drawn into fine wire from a button which had been completely fused with an oxyhydrogen blowpipe, was found to be 21·16. The aggregate sp. gr. of the cake of metallic mud when first introduced into the barrel, exclusive of moisture, is about 4·3: when taken out from the press it is about 10: that of the cake fully contracted on being taken out of the wind furnace before forging, is from 17 to 17·7. The mean sp. gr. of the platinum, after forging, is about 21·25, although that of some rods, after being drawn, is 21·4; but that of fine platinum wire is 21·5, the maximum specific gravity. The mean tenacity, determined by the weights required to break them, of 2 fine platinum wires, one of $\frac{1}{3000}$, the other of $\frac{1}{3850}$th of an inch in diameter, reduced to the standard of a wire $\frac{1}{10}$th inch in diameter, was 409 lbs. The mean tenacity of 11 wires, beginning with $\frac{1}{4500}$, and ending with $\frac{1}{25000}$th of an inch, reduced to the former standard, was 589 lbs.; the maximum being 645, and the minimum 480 lbs.[1]

Platinum, united in compact masses, is harder than copper, but softer than iron. It exceeds in tenacity all the metals except iron and copper. Next to gold and silver, it is the most ductile of the metals, and may be drawn out into wires $\frac{1}{1940}$th inch in diameter, but when enclosed within a silver wire it may be reduced to $\frac{1}{5000}$th and even to $\frac{1}{30000}$th of an inch in thickness, but in the latter case the wire is not coherent in long pieces. Platinum may be beaten out into very thin laminæ, like gold-leaf. A small proportion of iridium makes it harder and less ductile. Platinum may be welded at a white heat: indeed, it is on this valuable property that Wollaston's process of rendering platinum malleable is founded. It does not fuse in the strongest heat of a forge; but if in contact with the fuel, a fusible alloy of silicium and platinum is formed. Platinum resists oxidation in the air at a red heat, as well as gold and silver, and is much harder and more difficult of fusion than those metals: it is not attacked either by sulphur or by mercury: it does not dissolve in any simple acid, so that nitric acid and sulphuric acid may be boiled in it; it dissolves in aqua regia, but less readily than gold. These properties cause platinum to be peculiarly adapted as a material for making chemical vessels. Stills of platinum are now commonly used in sulphuric acid works.[2] The metals and the oxides of easily fusible metals, must not be fused in vessels of platinum, for they will form alloys with it; platinum is attacked by the caustic alkalies at a red heat, but not by the alkaline carbonates. When platinum is heated in presence of arsenic, phosphorus, and some other bodies, it loses its malleability and ductility. A mixture of silica and carbon produces a similar effect, as already noticed; hence platinum vessels should not be exposed to the direct action of fuel, but be encased in an earthen crucible containing a little magnesia and caustic lime.

Platinum exists in two states of minute division, viz. *spongy platinum*, in which the metal is in its crystalline state; and *platinum black*, which is amorphous.

Spongy platinum is obtained by igniting the ammonio-chloride of platinum, as in Wollaston's process already noticed. The remarkable property of this metal in determining the union of oxygen and hydrogen gases has been noticed under HYDROGEN, in describing the Döbereiner lamp, Fig. 1189. This property is exerted still more energetically by platinum black, in which the metal is in a more minutely divided state than in the sponge. It is prepared by boiling a solution of chloride of platinum, to which an excess of carbonate of soda and a quantity of sugar have been added, until the precipitate formed after a short time becomes quite black, and the supernatant liquid colourless. The black powder is collected on a filter, washed, and dried by a gentle heat. This substance has the property of condensing gases into its pores, especially oxygen, and it is constantly employed in the laboratory in eudiometrical experiments for exploding the mixed gases:[3] when placed in contact with a solution of formic acid it converts it into carbonic acid with abundant effervescence: alcohol and ether, dropped upon platinum black, become oxidised, and form acetic acid: indeed, one of the methods of forming vinegar from alcohol is founded on this property. See ACETIC ACID.

Platinum forms two compounds with oxygen, PtO and PtO_2: there are also two chlorides, $PtCl$ and $PtCl_2$. For an account of these and other compounds, we must refer to works on scientific chemistry.

PLINTH, from πλίνθος, a brick; a flat, square tile, sometimes also called the *slipper*, used as the foot or foundation of columns under the mouldings of the base and pedestal. It is also named *orle* or *orlo*. The *plinth of a statue* is a base or stand, and may be flat, round, or square. The *plinth of a wall* is a term applied to two or three rows of bricks advancing out from the wall; or, in general, for any flat high moulding, serving in a front wall to mark the floors, or to sustain the eaves of a wall and the lamier of a chimney.

PLOTTING is the art of describing or laying down on paper, the several angles and lines of a tract of ground surveyed by a theodolite and a chain. See SURVEYING.

PLUMBAGO. See BLACK-LEAD.

PLUMBING. The business of the plumber is to cover roofs and flats with sheet-lead, to lay gutters, to cover hips, ridges, and valleys, to fix water-trunks,

(1) Philosophical Transactions for 1829.

(2) In the Great Exhibition, M. Quennessen exhibited a platinum alembic for sulphuric acid, of the capacity of 250 pints, made in one piece, without seam or solder. The price, we believe, exceeded £800, a sum which is not unfrequently paid for a large platinum vessel.

(3) A very full notice of the action of platinum in various forms upon gases, is given in the second volume of Gmelin's *Handbook*.

to construct cisterns and reservoirs, to lay on the requisite pipes and cocks to them, to fix water-closet apparatus, and to erect pumps, &c.

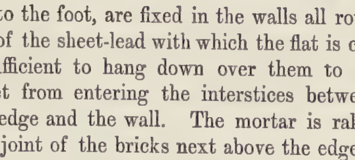
In covering terraces or flats with sheet-lead, a thickness or weight of 8 lbs. to the foot should be used. A level bottom must be first laid of plaster or of boards; the latter of sufficient substance to prevent warping, or the lead will be uneven and liable to crack. As the sheets of lead do not exceed 6 feet in breadth, and, if cast, 16 or 18 feet in length, and if milled, 25 feet in length, water-tight joints are required in covering large surfaces. They are made by forming *laps* or *rolls*. A roll is a strip of wood R, Fig. 1664, about 2 inches square, rounded on its upper side, nailed under the joint of the sheets where the

Fig. 1664.

edges overlap: one of these edges is dressed up over the roll on the inside, and the other is dressed over them both on the outside, by which means the water cannot penetrate. No fastening is required; the hammering of the sheets together down upon the flat being sufficient. When rolls cannot be used, *seams* must be resorted to: the approximate edges of the lead are bent up over against each other, and dressed down close to the flat throughout their length. This is not equal to the roll-joint: but the joints may be secured by soldering, which, however, is not advisable, since the variations in temperature cause the lead to crack. Indeed, it may be taken as a general rule, that solder should not be used unless absolutely necessary. Leaden flats and gutters should be always laid with a fall or *current*, as it is called, to keep them dry. The fall is usually made from back to front, or in the direction of the length of the sheet: ¼ of an inch to the foot is a sufficient inclination, and this is provided for by the carpenter while preparing the ground or platform on which the lead is to be laid. For hips and ridges, lead of 6 lbs. to the foot is sufficiently thick.

In making gutters, &c. pieces of milled lead, called *flashings*, F, Fig. 1665, about 8 or 9 inches wide, and

Fig. 1665.



5 lbs. to the foot, are fixed in the walls all round the edges of the sheet-lead with which the flat is covered, and sufficient to hang down over them to prevent the wet from entering the interstices between the raised edge and the wall. The mortar is raked out of the joint of the bricks next above the edge of the sheet, and the flashings are inserted into the crack at the upper sides, and their lower edges are dressed over those of the lead in the flat or gutter. Or the flashings may be fastened with wall-hooks, and their lower edges dressed down. In Fig. 1665, G B is the gutter-board, E P the eaves-board, and F E the foot of the eaves course.

Drips in flats or gutters are formed by raising one part above another, and dressing the lead in the manner described for covering the rolls. They are resorted to when the gutter or flat exceeds the length of the sheet, and they render soldering unnecessary.

Cisterns are usually of wood or masonry on the outside, lined with sheet-lead, and soldered at the joints. Water-trunks and pipes are made of a specified number of pounds weight to the yard in length. They are fitted with large *case heads* above to receive water from gutter spouts, and with *shoes* to deliver the water below. They are attached to the walls of buildings with flanches of lead, and secured by means of spike nails. Iron hold-fasts are used for attaching and supporting service and waste-pipes. See Pump.

From the nature of his material the plumber requires but few tools. He has a hammer, wooden mallets of different sizes, and a *dressing and flatting tool*. This last is of beech, about 18 inches long and 2½ inches square, placed smooth and flat on the under surface, rounded on the upper, and one of its ends tapered off round as a handle. With this tool the plumber stretches out and flattens the sheet-lead, or dresses it to the shape required, using first the flat side, and then the round one, as occasion may require. The plumber also uses a *jack* and a *trying* plane, for reducing the edges of sheet-lead to a straight line. His cutting tools are *chisels*, *gouges*, and *knives*, the last for cutting the sheet-lead into slips and pieces after it has been marked out by the chalk line. He also uses files and the usual apparatus for soldering.

Plumber's work is usually estimated by the cwt. of 112 lbs.: but some articles are taken by the pound weight, by number, and even by size. The prices of the various articles, from sheets of lead and pipes, to the cocks, bosses, ferules, valves, balls, traps, &c., being taken at their wholesale prices, an addition of 30 per cent. will usually repay the tradesman for ordinary expenses and profit, with the exception of carriage. It is stated, however, that plumbers often charge for sheet-lead and labour at so much per cwt.; for pipe of a certain bore at so much per foot; for so many joints in pipe of such a size, that is, for the labour and solder consumed and expended in making them; the account winding up at length with a separate charge for solder or for labour. This is actually charging twice over. Such being the "custom of the trade," as it is termed, the law courts have sanctioned these improper charges; but, as Professor Hosking properly observes, "the now prevalent custom of artificers' work being done by general builders by tender and contract, has considerably lessened the injury to the public from this abuse, and proved it to be really so by the moderate profits the same men will content themselves with if they make a tender, who would persist in charging at the old rate if they were instructed to do the work without being bound by a contract."[1]

(1) Encyclopædia Britannica, article *Building*.

PLUSH. A textile fabric, with a sort of velvet nap or shag on one side. See WEAVING.

POINT NET. A style of lace formerly much in fashion, but now superseded by the bobbin net manufacture. See the section *Lace*, in the article WEAVING.

POLISHING. See GRINDING AND POLISHING.

PONTOON. A barge or flat-bottomed boat, used in the formation of floating bridges for military purposes.

Bridges consisting of timber platforms supported on floating vessels, are of great antiquity; and they have at all times occupied much of the attention of military engineers. One of the latest forms of pontoon is that by Colonel Pasley: it is in the form of a canoe, with decks, and is 22 feet long, and with a breadth and depth of 2 feet 8 inches. One end is shaped like the head of a boat, in order that it may be moved through the water, by rowing, with either end foremost: it is constructed of light timber frame, covered with sheet copper, except the deck. Each vessel is formed in two equal parts by transverse partitions, so that the demi-pontoons may be separated from each other when the bridge is to be conveyed on carriages by land with the army. In the water the parts are connected together by a rope, which passes through two perforations in the keel near the point of junction, and by a rectangular frame of wood attached along the deck by lashings. Each half vessel is also divided into two compartments by a partition. Small pumps are provided, by means of which the pontoons may for a time be kept afloat should a hole be made in the side by a shot or other accident.

Cylindrical pontoons of tin, 22 feet long and 2½ feet in diameter, invented by Colonel Blanchard, have been introduced into the service. These have hemispherical ends, and are divided longitudinally and transversely into several compartments by tin partitions, to increase their strength and to prevent them from sinking if perforated in any part. These pontoons are light and buoyant, but are said to be less durable than Pasley's copper pontoons, and more liable to injury when transported by land.

The method of forming a bridge is nearly the same with either kind of pontoon. A rectangular frame, the length of which is about equal to the breadth of the platform of the intended bridge, viz. 12 feet, is laid down longitudinally on the deck of the canoe, or on the surface of the cylinder, and is kept in its place by rope lashings. On the upper surface of this frame, in the direction of its breadth, are nailed pieces of wood, in pairs, at equal intervals; the distance between every two in each pair being little more than equal to the breadth of a baulk or joist (2½ inches), one extremity of which is to be received between them, and the number of pairs being equal to the number of baulks which are to support the *chesses* or planks forming the roadway. A raft is formed with two of these pontoons by placing them parallel to each other at a distance from centre to centre equal to about 12½ feet; the ends of two bulks or *transoms* are made to rest upon the frames, the distance between them being equal to the intended breadth of the bridge; and they are kept steady by having near each extremity a hole bored through them, into which enters an iron pin fixed vertically in the frame; they are also made fast to the pontoon by ropes passing through rings on the decks. Three or more baulks are then laid down parallel to the transoms, with their extremities confined between the cross-pieces nailed to the frames: the chesses are laid close together above them, and their ends are kept down by ribands attached to the transoms by lashings passing over them, and under the latter at intervals. Rowlock pins are fixed in the ribands, and when the bridge is not formed, the ribands being then parallel to the lengths of the pontoons, at the sides of the raft, the latter may be moved on the water by oars. In forming the bridge a certain number of such rafts are rowed to their stations in a line across the river, and anchored with the lengths of the pontoons parallel to the banks; the distances between the nearest pontoons in two rafts being equal to that between the two pontoons in each raft. Each raft, then, carrying the materials for constructing a platform over the water between itself and the next, is laid down in a manner similar to that for laying down the platform of the raft, and from each of the extreme pontoons a similar platform is extended to the shore of the river.

Under favourable circumstances, the complement of men attached to each raft of two pontoons, viz. 1 non-commissioned officer and 6 privates, can dismount two vessels and their stores from the carriages, launch them, and form the raft in a quarter of an hour. All the rafts being put together at the same time, the whole bridge may be formed in another ¼ of an hour. When the passage has been effected, the bridge can be dismantled in eight minutes; the rafts can then be taken to pieces and the vessels and stores repacked on the carriages in ¼ of an hour. A cart with 2 wheels may be used for conveying each pontoon; the latter is separated into 2 demi-pontoons, which are placed side by side above their stores.[1]

Details of military operations do not enter into the plan of this work; but we give the above as an example of successful bridge engineering. The various forms of boat bridges, bridges on rafts of timber, casks, &c., are detailed in the work of Sir Howard Douglas on Military Bridges. Second Edition, 1832.

POPLAR. See WOOD.

POPPY. See OPIUM.

PORCELAIN. See POTTERY and PORCELAIN.

POROSITY. The minute particles of which a body consists are so arranged as to leave certain intervals or spaces between them. This arrangement is termed *porosity*, and the spaces themselves are named *pores*. In some cases, as in sponge and cork, they are large enough to be seen by the unassisted eye, in others they require the aid of a microscope. Their visibility

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(1) A lithographed pamphlet of 70 pages 8vo. was prepared in 1823, entitled, "Exercise of the New-decked Pontoons or Double Canoes, invented by Lieut.-Colonel Pasley, R.E. Lithographed at the Establishment of Field Instruction, Royal Engineers' Department, Chatham."

by either means is not, however, necessary to prove their existence. All bodies, even the most compact, may be diminished in bulk, either by mechanical force or by reduction of temperature, which could not be the case if the particles were actually in contact, or so aggregated as to leave no interstitial spaces. When, therefore, a body expands, the distance of its particles from each other is increased, and conversely, when a body contracts or diminishes in bulk, its particles approach each other. The porosity of bodies is also inferred from their elasticity. Liquids also appear to be porous. When salt is dissolved in water, the volume of the mixture is less than the sum of the volumes of the substances when separate. The particles of the salt appear to introduce themselves between the particles of the water. Alcohol and water furnish another example of this apparent penetration of matter. The porosity of matter is taken advantage of in the purification of liquids by filtration; paper, solid stone, sand, &c., being used for the purpose. See FILTRATION.

PORPHYRY. In the short classification of the granites, given in the INTRODUCTORY ESSAY, page lxxix., granite, with distinct additional crystals of felspar, is termed *porphyritic granite*. The term *porphyry* is usually applied to felspar containing imbedded crystals of the same substance. The methods of working it for ornamental purposes are noticed under GRANITE. For its application to the making of slabs, mullers, and mortars, see TRITURATION.

PORTER. See BEER.

PORTLAND STONE, a fine compact oolite, named from the island where it is quarried. See STONE.

POSTS, KING and QUEEN. See CARPENTRY, Figs. 511, 512.

POT-METAL, an alloy of copper and lead. Ordinary pot-metal, 6 oz. of lead to every pound of copper, is called *dry pot-metal*, because this proportion of lead is taken up without separating on cooling. It is brittle when warmed. The proportion of 8 oz. of lead produces an inferior pot-metal, named *wet pot-metal*, because the lead oozes out on cooling. This is especially the case when new metals are used, hence it is customary to fill the crucible with old metal and make up the required quantity with new. This alloy becomes very brittle on a slight application of heat. The addition of tin improves pot-metal; but if the tin be in excess, the alloy resembles gun-metal. A small proportion of zinc may be added, but with this metal, the tendency is for the copper to combine with it to form brass to the exclusion of the lead. Antimony assists the combination of the constituents of pot-metal. Mr. Holtzapffel states that 7 lead, 1 antimony, and 16 copper mix well at the first fusion, and form apparently a superior metal to 4 lead and 16 copper.

POTASH. See POTASSIUM.

POTASSIUM (K40), the metallic base of the alkali potash, a substance widely diffused in nature, but always in combination with other bodies. Many of the minerals which compose the crystalline rocks, such as the felspars, micas, &c., contain silicate of potash. As these rocks crumble down into soils, the potash assumes a soluble form, and is gradually taken up by plants, and accumulated in their substance in conjunction with organic acids: thus potash in the vine is combined with tartaric acid, in woodsorrel with oxalic acid, and so on. When plants are burned these acids are destroyed, and the base, potash, is obtained in the form of carbonate.

The compound nature of potash was first demonstrated in 1807 by Sir H. Davy. By exposing moistened hydrate of potash to the action of a powerful voltaic battery, water and potash were simultaneously decomposed, oxygen being evolved at the positive electrode, while hydrogen and potassium were separated at the negative. The battery was so exceedingly powerful that the metallic globules generally took fire as soon as they came in contact with the air, but by carefully scraping them off into naphtha as they appeared, a supply was obtained for the purposes of experiment.

A method of decomposing potash by chemical means was soon after invented by Gay Lussac, and, as improved by Brunner, is now adopted for obtaining the metal in large quantities. It is as follows:—The tartrate of potash, or crude tartar of commerce, is calcined in a covered iron pot, and is thus converted into carbonate of potash, mixed with minutely divided carbon. This mass, while still hot, is to be intimately mixed with about one-tenth part of charcoal in small lumps, the effect of which is to make the mass sufficiently porous to allow of the escape of gas. The whole is quickly introduced into an iron bottle (such as is used for importing mercury), and a short but rather wide tube is fitted to the aperture. The bottle is placed horizontally in a wind furnace, so constructed that the flame of a strong fire, fed with dry wood, may wrap round it, and keep up a uniform heat approaching to whiteness. To the short iron pipe is attached a copper receiver or condenser, partly filled with rectified naphtha, and so constructed with partitions as to exclude the air. The receiver is kept cool by means of ice applied to the outside. Through the receiver is passed a stout iron wire, terminated by a screw, for clearing the iron tube of any solid matters that condense in it. When the iron bottle has attained the required temperature, the decomposition of the alkali by the charcoal begins; the oxygen of the potash and of the carbonic acid combines with the carbon, forming carbonic oxide gas, which is disengaged in abundance, while the potassium distils over, and condenses in the receiver in globules. The operation is liable to fail from the tendency of the carbonic oxide and the potassium to form a dark grey compound, which sublimes and condenses in the short iron tube, from which it must be removed by the application of the screw wire. When the operation is most successful, at least one-half of the metal is lost by combining with carbonic oxide. The potassium which passes over is contaminated with carbon and this grey compound: it may be obtained pure by distilling it in a cast-iron retort

containing a little naphtha, the vapour of which expels the air. The pure metal is thus obtained in globules, which may be preserved in naphtha quite free from oxygen. The potassium may also be purified by tying it up in a linen bag, heating it to 140° or 150°, and squeezing out the metal under naphtha with a pair of wooden pliers.

Potassium appears of a bluish white colour and metallic lustre when a globule is freshly cut open. At common temperatures it is soft and may be moulded in the fingers like wax. At 32° it is brittle and crystallizes in cubes; at 70° it becomes pasty, and liquid at 150°. It boils at a dull red heat, forming a green vapour. Its sp. gr. is 0·865. So powerful is the affinity of this metal for oxygen, that it instantly oxidizes on exposure to the air; the surface becomes tarnished, and a crust of caustic potash is formed. This strong affinity for oxygen causes it to decompose water and even ice, and the evolved hydrogen gas and a portion of the metal inflame and burn with a fine violet colour. When thrown on the surface of water the ignited globule moves about with rapidity, and when the metal is entirely consumed, a globule of fused dry potash combines at a certain temperature with the water, with a crackling explosion, and dissolves, forming a solution of potash.

Potassium combines with oxygen in two proportions, forming the *protoxide* KO and the *peroxide* KO_3.

The protoxide of potassium, known as *potassa*, or more familiarly, *potash*, is a substance of great importance in chemistry, pharmacy, and the useful arts. The only known method of obtaining it free from water, is by exposing potassium to dry air, when it forms a white powder, fusible at a red heat, and volatile at a white heat. If once united with water, it cannot be separated from it except by means of an acid. The potash of commerce and that used in the laboratory is always hydrated. Before carbonic acid was known, the alkalies and their carbonates were distinguished by the terms *caustic* and *mild*, and it is still not unusual to name the hydrate of potash, *caustic potash*. See ALKALI.

The hydrate of potash is prepared for use by decomposing the carbonate by means of hydrate of lime: 10 parts of carbonate of potash are dissolved in 100 parts of water, and the solution boiled briskly in a clean vessel of untinned iron (silver is used for scientific purposes): 8 parts of good quicklime are in the meantime to be slaked in a covered basin, and the hydrate of lime thus formed added by degrees to the boiling solution with frequent stirring: the lime abstracts the carbonic acid from the potash, and carbonate of lime is formed and rapidly deposited. When all the lime has been stirred in, the mixture is allowed to boil for a few minutes, and is then removed from the fire and covered up to exclude the air. In a short time the solution will have become quite clear, and may be syphoned off. The solution if properly prepared, will not effervesce on the addition of muriatic acid, showing that all the carbonic acid has been transferred from the potash to the lime. The solution of caustic potash is rapidly evaporated in an iron vessel as far as may be desired: if heated until vapour of water ceases to be disengaged and then allowed to cool, it forms the solid hydrate, KO, HO. But instead of being allowed to cool in this form, it is usually run into cylindrical moulds, Fig. 1666. The mould is in two halves, which admit of being screwed together so as to form a tight joint. The

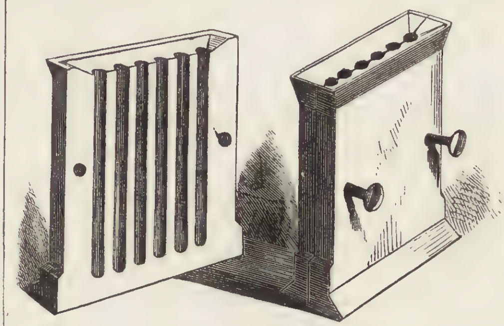


Fig. 1666.

fused potash is poured into the trough at the top, and when it is solidified, the sticks are taken out by unscrewing the mould. The sticks thus produced form the *caustic potash* or *fused potash* of the shops, and are used by surgeons as a cautery. In this state, however, it is not pure; it contains sulphate and carbonate of potash, chloride and peroxide of potassium, and oxide of iron; it may be purified by dissolving it in absolute alcohol, evaporating to dryness, and fusing the remaining potash a second time. The pure hydrate is a white solid substance, very deliquescent, and dissolving in water with considerable rise in temperature. It imparts to the fingers a peculiar soapy feel, in consequence of its dissolving the cuticle; it dissolves and decomposes the organic tissues, whence its use in surgery and its name of caustic potash. It unites with the fat oils to form soap, whence its aqueous solution is termed *soap-lye*. [See SOAP.] It is powerfully alkaline, completely neutralizing the most powerful acids; and being the strongest base it is employed in most cases of saline decomposition: indeed, its uses in chemistry and the arts are innumerable; it restores the blue colour to reddened litmus, and turns the yellow of turmeric paper brown; it has a nauseous and peculiar taste; it absorbs carbonic acid rapidly from the air, and must therefore be preserved in well-stoppled bottles of common green glass, as it acts rapidly on glass containing much alkali or lead.

The following table shows the densities and value in real alkali of different solutions of hydrate of potash, together with the boiling points:—

Sp. Gr.	Potash per cent.	Boiling point.
1·68	51·2	329°
1·60	46·7	290
1·52	42·9	276
1·47	39·6	265
1·44	36·8	255
1·42	34·4	246
1·39	32·4	240
1·36	29·4	234
1·33	26·3	229

Sp. Gr.	Potash per cent.	Boiling point.
1·28	23·4	224°
1·23	19·5	220
1·19	16·2	218
1·15	13·0	215
1·11	9·5	214
1·06	4·7	213

Peroxide of potassium, KO_3, is formed when potassium is burned in excess of dry oxygen gas. It is also produced when nitre is decomposed by a strong heat, and also to a small extent by long exposure of hydrate of potash to the air. It is an orange-yellow fusible substance, and is decomposed by water into potash and oxygen gas.

Carbonate of potash, $KO,CO_2,2HO$. The large demand for carbonate of potash by our various chemical manufactories, is almost entirely supplied by the combustion of vegetables, and hence the production is for the most part confined to countries where timber is superabundant, such as North America. The sap of plants contains various soluble salts, chiefly those of potash and of soda, in combination with certain organic acids as already noticed. These acids are compounds of carbon, hydrogen and oxygen, and when the plants are burnt the acids are destroyed, while the potash and soda remain in the ashes in the form of carbonates, these bases not losing their carbonic acid by heat, as is the case with the earths, lime, &c. The ashes also contain other salts, such as chlorides of potassium and of sodium, sulphates of potash and of soda, carbonates and phosphates of lime and of magnesia, and silicate of alumina. Plants which grow near the sea mostly contain soda; inland plants potash. The ashes of the latter are lixiviated with water in a large cask or tun, Fig. 1667, furnished with a false perforated bottom, which is covered with straw, and between this and the real bottom is an aperture *o* stopped by a plug. A pipe *p* extends from the top of the tub through the perforated bottom to allow the air to escape freely from the space between the true and the false bottom.

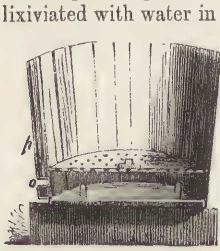


Fig. 1667.

After some hours the liquid is drawn off, and more water added in order that the whole of the soluble matter may be removed. The weakest solutions are poured upon fresh quantities of ash instead of water. In this process the soluble salts, such as the carbonates of potash and of soda, the chlorides and the sulphates, are dissolved. The insoluble residue consists principally of silicate of alumina, and carbonate and phosphate of lime. The solutions or *leys* are evaporated to dryness and the residue calcined to remove a little brown organic matter, and the product thus obtained forms the *crude potashes* of commerce. These are classified according to the locality whence they are imported, or according to the route by which they arrive; thus there are *American, Russian, Turkey, German, Moselle, Illyrian, Saxon, Bohemian, Dantzig*, and *Heidelberg potashes*, and these are seldom distinguished by their colour or appearance, as is the case with *pearl-ash*, as the calcined potash is termed when it has a white pearly lustre.

The weight of ashes furnished by different plants varies in different species and soils. Herbaceous plants yield more than woody ones, and different parts of the same plant furnish very different proportions of ash; the leaves yield more than the branches, and the bark more than the trunk. Thus Saussure found in the pealed branches of oak 29 times as much ash as in the wood; in the bark 30 times; in the inner bark 36 times; in the sap-wood twice, and in the leaves 36 times as much. In white beech the sap-wood contained 1·1 times the bark, 22 times as much as the wood. Although potash can only be produced on a large scale in countries where timber is abundant, yet the ashes of wood fuel are turned to useful account in all countries, either as manure or as a soap in washing linen. In some thinly populated countries, as in the United States of America and the North of Europe, where wood is very abundant, it is burned solely for the sake of the ash. In Russia, where manure is not of much value, straw and weeds are consumed for the same purpose. In the north of France yeast, the lees of wine, and the residue of the brandy distilleries, are made into cakes, dried in the sun, and burnt for the sake of the ash. In Java the stems and leaves of the indigo plant, after the separation of the colouring matter, are used for making potashes. Formerly the crude ash was sent into the market, but this practice has long been discontinued. The soluble portion is now extracted by means of water, the lye is evaporated, and the residue heated to redness as above described.

The composition of crude potash is variable, and as its value depends chiefly on the proportion of alkaline carbonate which it contains, it is of importance to the manufacturer to be able to test the value of the potashes as they come before him. Instructions for the purpose will be found under ALKALIMETRY.[1] Crude potash contains from 60 to 80 per cent. of carbonates of potash and of soda; the remainder consists of sulphate of potash, chloride of potassium, and a small quantity of silicate of potash. It may be purified by solution, and a carbonate of potash obtained with only 2 or 3 per cent. of foreign matters. For this purpose the crude potash is treated with its weight of cold water, and left to digest during several days with occasional agitation; the sulphate of potash and chloride of potassium, being less soluble than the other salts, remain for the most part as residue. The liquor is syphoned off and rapidly evaporated, until small crystals are deposited; the fire is then withdrawn and the liquor left to cool. While the crystallization is going on, the liquor is kept in agitation, in order that small crystals only may be formed. When

(1) A good account of potash and the method of estimating its value is given in the first volume of "Knapp's Chemical Technology," translated by Drs. Ronalds and Richardson, 1848. This volume also contains a full account of nitre. Dumas has also some admirable chapters on the subject of potash; but the fullest chemical account that we are acquainted with is in "Gmelin's Handbook," vol. iii.

the liquor is cold it is discharged into a filtering bed, which retains the crystals of carbonate of potash, and these are washed with a small quantity of pure carbonate of potash, and then dried at a stove.

A yet purer carbonate of potash may be obtained by decomposing cream of tartar, *i.e.* bitartrate of potash, by means of heat, in an iron pot. The residue consists of a mixture of carbonate of potash and of carbon, which is sometimes employed in the laboratory under the name of *black flux.* The carbonate of potash is dissolved out by means of water, and the solution evaporated to dryness. Carbonate of potash is also prepared by projecting small portions at a time of a mixture of 1 part cream of tartar, and 2 parts nitrate of potash, into an iron pot heated to redness. The carbon of the tartaric acid is completely burned by the oxygen of the nitric acid, and there remains a white substance, termed *white flux,* which consists almost entirely of carbonate of potash. It is, however, contaminated with a little nitrate of potash.

Carbonate of potash is very deliquescent, and is soluble in less than its own weight of water; the solution is very alkaline. This salt is insoluble in alcohol. When exposed to heat the water of crystallization is driven off, and at full ignition the salt fuses, but is not otherwise changed.

Bicarbonate of potash, KO,CO_2+HO,CO_2. This substance is obtained by passing a stream of carbonic acid through a cold solution of potash; the gas is rapidly absorbed, and a white crystalline substance separated. It is collected, pressed, redissolved in warm water, and left to crystallize. It forms large and beautiful crystals, the form of which is derived from a right rhombic prism. On the continent the supply of carbonic acid for this manufacture is economically obtained from the fermentation of sweet wines and liqueurs, and in some localities the carbonic acid disengaged from the earth is employed for the purpose.

Bicarbonate of potash is much less soluble than the simple carbonate, 4 parts of cold water being required for solution; the solution has a milder taste than that of the former salt, and is nearly neutral to test paper. Carbonic acid is disengaged by boiling the solution; the crystals are also decomposed by heat, water and carbonic acid being evolved; and the simple carbonate remains.

Nitrate of potash, KO,NO_5. This salt, also named *nitre* or *saltpetre,* is a natural product, but may be prepared by the addition of nitric acid to potash, or to carbonate of potash. The liquor, on being evaporated, deposits anhydrous crystals, which are six-sided prisms with dihedral summits. This salt is soluble in 7 parts of water at 60°, and in its own weight of boiling water. It has a cooling and saline taste, but has no action on vegetable colours. It fuses at a temperature below redness, and is completely decomposed under a strong heat. When mixed with combustible matter and heated, or thrown in a fused state on many metals, rapid oxidation takes place at the expense of the oxygen of the nitric acid. Gunpowder is an example of such a mixture, and there are many such in various pyrotechnic compositions, which burn independently of the atmospheric air, and even under water, oxygen being abundantly supplied by the nitric acid. See GUNPOWDER.

In India, Egypt, and some other warm countries, after the rainy season, nitre is produced on the surface of the soil in the form of a white efflorescence. The soil is removed to the depth of about an inch, and treated with water, which dissolves the soluble salts. The solution is made in large basins or tanks; rapid evaporation takes place under the influence of the solar heat, and is completed by means of artificial heat: as the solution cools, a considerable quantity of nitrate of potash is deposited in large crystals. This forms *rough Indian nitre.* The mother liquor is thrown away; it contains a considerable quantity of nitrate of lime and magnesia, and might still furnish nitre if mixed with potash salts. Bengal and the neighbourhood of Patna are the sources of the largest portion of the saltpetre supplied to the European market from Hoogly. In Hungary there are saltpetre pits, and in some parts of Spain the soil becomes incrusted with this substance.

Nitre is also obtained from certain natural caverns occurring in the limestone rocks of the island of Ceylon: the walls become covered with a nitrous efflorescence, which is detached, during six months of the year, with picks, together with a small portion of the rock which contains felspar, and this is doubtless the origin of the potash. The fragments are pounded, mixed with an equal portion of wood-ashes, and water is poured upon the mixture. The nitrates of the earths part with their acid to the potash in the ashes, and the earths are precipitated as carbonates of lime and magnesia. The clear decanted lye, containing the nitre of the ashes as well as that of the rock, is evaporated in pits exposed to the sun, and then in pans by the action of fire. The crude saltpetre, which crystallizes in cooling, is then fit for exportation. Similar caves exist in Italy, on the coast of the Adriatic, in North America, Africa, Teneriffe, &c.

In France, nitre was formerly produced artificially in what are termed *nitre-beds,* by the oxidation of ammonia in the presence of a powerful base. Animal refuse of all kinds was mixed with old mortar, or hydrate of lime and earth, and the mixture was placed in heaps under a cover of some kind, to keep off the rain, but with free exposure to air. The heaps were watered from time to time with stale urine, and the mass was turned over in order to expose fresh surfaces to the air. When a considerable quantity of the salt had been formed, the mixture was lixiviated, in troughs of oak-wood, Fig. 1668. In one of the longer sides of each trough, between the stays *s s,* were holes *h h,* for the reception of tubes or cocks to conduct the fluid into the gutter *g;* and in order to keep back the earth, &c., an inclined board pierced with holes was placed inside, as shown at *b,* Fig. 1669, and this was covered with straw or willow twigs. The iron rods *r* prevented the sides from bulging. The solution was pumped up several times from the

gutters, and when it had passed repeatedly through the trough, it formed the *crude lye.* This contained

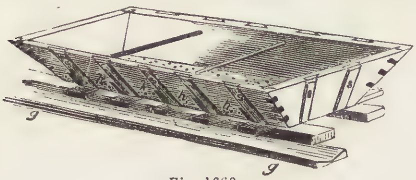


Fig. 1668.

nitrate of lime, mixed with carbonate of potash: carbonate of lime was formed while the nitric acid passed

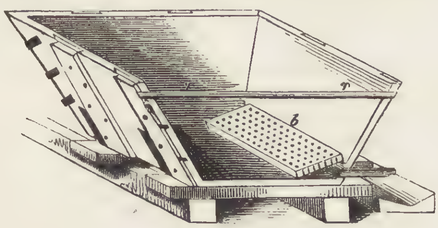


Fig. 1669.

over to the potash. This solution was then evaporated to the crystallizing point by boiling in large coppers similar to that shown in Fig. 1670. The scum was removed by proper tools into a vessel above the level of the copper, so that the water might drain back into the copper. Earthy matters in the salt would tend to form a deposit, but the currents produced by the ebullition caused them to circulate, and as the heat was greatest near the sides, the currents would there be ascending ones of considerable force; the descending currents, on the contrary, would be formed among the central and cooler portions of the liquid; so that the earthy matters raised by the ascending currents at the side would be carried along to the

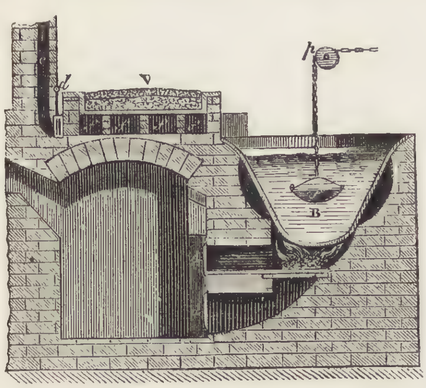


Fig. 1670.

centre and descend with the liquid. Now by an ingenious contrivance a small vessel *v*, Fig. 1670, was suspended by a chain and pulley *p* in the centre of the vessel, and the earthy matters, instead of falling to the bottom of the boiler in the downward course, were received and retained by this small vessel, while the water of the downward current passed over its sides to the bottom. Every now and then the vessel *v* was raised, and its contents turned out, and in this way a large proportion of the earthy matter was separated. The solution thus concentrated by boiling was next crystallized, and the crystals were purified by being dissolved and crystallized several times.[1] Now that nitre is freely imported into France from foreign parts, this plan, which is tedious and costly, is no longer adopted; but it was, in its origin, of great importance to France, when that country, towards the end of the last century, was surrounded by enemies, and all communications with foreign countries cut off. By this method alone was she able to procure supplies of saltpetre for the manufacture of gunpowder, and one of her most illustrious chemists, Berthollet, traversed France from one extremity to the other, giving instructions for carrying out the plan. At the present time there are, however, in Prussia, Sweden, and other parts of Europe, what are called *saltpetre plantations, walls,* and *heaps,* in which this salt is artificially produced.

In populous towns, where the excrements of animals, refuse from slaughter-houses and various trades, the water from the houses, the refuse of markets, &c., mix with the fluid matter of the drains and are in a constant state of putrefaction, the coating of mortar on external walls, especially at the base, becomes covered with a white, floccular, crystalline efflorescence: this causes much injury to buildings, and is known as *saltpetreing* or *saltpetre rot.* The same phenomenon also occurs in other parts of the walls not so exposed. See Plastering.

The rough nitre as imported into Great Britain from the East Indies, is in broken crystals of a brown colour, and more or less deliquescent. The loss which it sustains in refining is termed the *refraction,* and can only be ascertained by analysis; but it is not easy to obtain a fair sample of a cargo. "The samples which the merchants and brokers select for analysis, generally consist of portions drawn from each bag and afterwards mixed together, and if carelessly or unfairly taken, or exposed so as to become more moist or more dry than the bulk, the report of the analyst is often unsatisfactory. He should work upon not less than 20 to 30 lbs. of such sample, which should be ground or triturated so as to produce a properly uniform mixture of the whole, for it often includes lumps of pure nitre or of other salts: from 100 to 1000 grains of this mixture is then taken for analysis. The moisture is determined by the loss occasioned by careful drying on the sand-bath: it is then dissolved in water and tested, so as to acquire some general notion of the impurities; and by means of nitrate of silver, nitrate of baryta and oxalate of ammonia, the proportion of chlorine, sulphuric acid, and lime may be determined: the lime is generally in the state of sulphate, and more or less sulphate of potassa is also usually present. The chlorine is chiefly derived from the chlorides of potassium and sodium. Another portion of the sample should be dissolved in about thrice its weight of boiling water and filtered, by which any sand or other insoluble impurities are

(1) The process is fully described in Thenard's *Traité de Chimie,* and also in Dumas, *Chimie Appliquée aux Arts,* tom. ii.

collected: the salt should then be crystallized in the usual way, during which the appearances and forms of the successive deposits will indicate, to the experienced eye, the nature of the foreign salts present, among which nitrate of soda, sulphate of potassa, sulphate and nitrate of lime, and chloride of sodium and potassium, with traces of chloride of calcium, and sometimes of a peculiar organic matter, are frequently found. It will be obvious that the accurate quantitative analysis of such a mixture of salts is not a very easy problem; and yet the separation of nitrate of soda from nitrate of potassa, and of chloride of potassium from chloride of sodium, are essential steps, as the value of the sample is affected by their relative proportions: for nitrate of soda, to say nothing of its unfitness for the manufacture of gunpowder, is cheaper than nitrate of potassa; and chloride of sodium is of no value, whereas chloride of potassium is purchased by the alum-makers; so that a sample of nitre, containing the latter salt, is in this respect worth more than where it only contains common salt. But inasmuch as the equivalent of chloride of sodium is only 60, and that of chloride of potassium 76, it is obvious that if the whole of the chlorine, as indicated by the weight of the chloride of silver, be considered as in combination with sodium (part of the sample consisting of chloride of potassium), the refraction will be estimated below the mark. Hence the necessity of ascertaining the relative proportions of both chlorides, which is best effected by converting them into sulphates and separating them by crystallization."[1]

The refining of nitre on a large scale is founded on the property that its solubility increases rapidly with the temperature, while the solubility of the chlorides of sodium and of potassium remains nearly constant. For example, about 25 cwt. of rough nitre is dissolved in the large copper boiler B, Fig. 1670, in 150 gallons of water; the heat is gradually raised, and fresh portions of nitre are added until about 60 cwt. have been dissolved. The solution is kept stirred, and the scum removed. The water in the boiler, when raised to the proper temperature, is sufficient to dissolve the whole of the saltpetre, but not the whole of the foreign salts: a large portion of the chloride of sodium subsides, and may be scooped out of the boiler. 100 gallons of water are then gradually added so as not to cool the solution too much; $2\frac{1}{4}$ lb. of glue dissolved in warm water are then poured in, and the whole thoroughly agitated. The glue thus diffused through the liquid becomes entangled with the organic substances which rendered the solution viscous, and rises with them to the surface in the form of scum, which is carefully removed, and after boiling for some time, the liquor becomes clear. The fire is then withdrawn and the temperature let down to about 195°, when the liquor is carefully dipped out and removed to the crystallizing vessels. The liquor must be disturbed as little as possible during this operation, in order not to suspend the crystals of common salt deposited at the bottom. The crystallizing vessel is a shallow copper vessel, the edge of which is firmly screwed to a platform of oak *t*, Fig. 1671. It is formed with two inclined planes, and purposely made deeper at one part *d*, Fig. 1672, than in any other. As

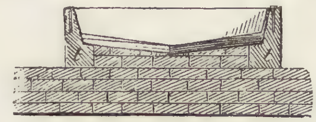


Fig. 1671.

the liquor cools, the crystals quickly form, and if left tranquil they are of large size and clustered

Fig. 1672.

together, the consequence of which is, that portions of the mother liquor become confined within the groups, and the nitre becomes contaminated with those very salts which it is the object of this refining process to remove. But if the liquid be constantly agitated during the crystallization, the salt forms into small prismatic crystals, from which the mother liquor can afterwards be readily removed by washing. As fast as the crystals are formed they are raked up towards the top of one of the inclined planes of the trough, and thus the mother liquor drains back into the liquid. As soon as the salt is dry it is removed to make way for the remainder of the crop of crystals, which are gathered until the liquor sinks down to near the temperature of the air. The crystals of saltpetre are next washed in tubs, one of which is shown in plan and section, Figs. 1673, 1674, containing a false bottom drilled with holes; the tub is filled with the salt and heaped up some inches

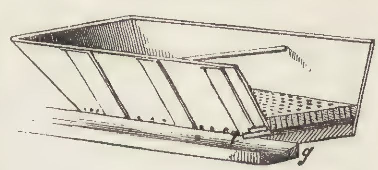


Fig. 1673.

above its rim. A cold saturated solution of pure nitrate of potash is poured over the salt so as thoroughly to wet the mass. Of course this solution is not capable of dissolving saltpetre, since it is already saturated with that salt, but it readily dis-

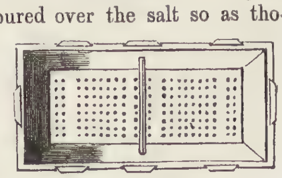


Fig. 1674.

solves the chlorides. The whole is left in this condition for some hours, after which the opening at *t* is unstopped, and the water flows off into the gutter *g*. When the salt is thoroughly drained, it is sprinkled with pure water, which is left upon the salt for a couple of hours; it is then drained off, saturated with nitrate of potash and containing some traces of chlorides. The saltpetre thus refined is dried in the shallow vessel V, Fig. 1670, which is heated by the flue, *f f*, of the furnace fire, which winds under it in its way to the chimney *c*, the draught being regulated by a damper *d*. The salt is continually stirred during the drying to prevent it from forming into masses.

(1) Brande, "Manual of Chemistry."

Sulphate of potash, KO,SO_3. In the manufacture of nitric acid from nitrate of potash [see NITRIC ACID], the acid residue left in the retort is dissolved in water and neutralized with crude carbonate of potash: the solution, on cooling, yields hard transparent crystals of the neutral sulphate, which may be purified by re-dissolving in boiling water, and recrystallizing. This salt is soluble in about 10 parts of cold, and in a much smaller quantity of boiling water: it has a bitter taste, and is neutral to test paper. The crystals are anhydrous and decrepitate when suddenly heated. They are insoluble in alcohol. There is a bisulphate of potash consisting of $KO,SO_3 + HO,SO_3$, and an anhydrous bisulphate consisting of $KO,2SO_3$.

Chlorate of potash, KO,ClO_5. When chlorine is passed into a warm and moderately strong solution of caustic potash, or of carbonate of potash, and the liquid concentrated by evaporation, flat tabular crystals of chlorate of potash are obtained. In this process a portion of the potash is decomposed, its oxygen combines with one portion of chlorine to form chloric acid, while the potassium is taken up by a second portion of chlorine, and chloride of potassium remains in the mother liquor. The reaction may be thus represented:—

6 equiv. chlorine { 5 eq. chlorine → 5 eq. chloride of potassium.
{ 1 eq. chlorine
6 equiv. potash { 5 eq. potassium
{ 5 eq. oxygen
{ 1 eq. potash → 1 eq. chlorate of potash.

The crystals of chlorate of potash are anhydrous, flat, and tabular: they are soluble in about 20 parts of cold and 2 of boiling water: their taste somewhat resembles that of nitre. This salt affords a ready means for obtaining oxygen gas. [See OXYGEN.] It deflagrates violently with combustible substances, and friction or percussion often produces explosion. A few grains of this salt and of sulphur rubbed up together in a mortar produce a series of loud crackling explosions. Attempts have been made to substitute this salt for nitre in the manufacture of gunpowder, but a number of fatal explosions rendered the application impossible. A large quantity of it is consumed in the manufacture of lucifer matches and fusees in conjunction with phosphorus. [See MATCHES—PHOSPHORUS.] All those matches which burst into a whitish flame with a slight explosion and a kind of roaring noise contain this salt. Those matches which ignite quietly on gentle friction, contain no chlorate of potash, but a good deal of common phosphorus.[1]

Iodide of potassium, KI, may be prepared by adding iodine to a strong solution of caustic potash: the iodine is largely dissolved, and a colourless solution formed of iodide of potassium and iodate of potash. The reaction is similar to that with chlorine and potash. When the solution begins to retain the colour of the iodine, it is evaporated to dryness, and cautiously raised to a red heat, which converts the iodate of potash into iodide of potassium. The mass is then dissolved in water, filtered, and crystallized. The crystals are in cubes often milk-white and opaque: they are anhydrous, but fuse readily when heated. They are soluble in water and in alcohol, and if pure, not deliquescent in tolerably dry air.

Bromide of potassium, KBr, may be formed in a similar manner, using bromine instead of iodine. It is a colourless, soluble salt, resembling the iodide.

Sulphurets of potassium. There are three distinct compounds of potassium and sulphur, viz. KS, KS_3, and KS_5. The *simple*, or *monosulphuret of potassium*, may be formed by the reduction of sulphate of potash at a red heat, by means of hydrogen or charcoal-powder. There are also other methods. It is a crystalline mass, of a cinnabar-red colour, very soluble in water: the solution has an offensive and caustic taste; it is readily decomposed by acids; sulphuretted hydrogen being evolved, and a salt of the acid used to decompose it, formed. This sulphuret is a strong sulphur base, and forms crystallizable saline compounds with the sulphurets of hydrogen, carbon, arsenic, &c. The higher sulphurets are obtained by fusing the simple sulphuret with different proportions of sulphur.

Our limits will not allow of a fuller notice of the various salts of potash; but we may conclude with a brief statement of their general properties. The salts of potash may in general be recognised—1. By their physical characters, but chiefly by those of the sulphate, an anhydrous and readily crystallizable and tolerably hard salt. 2. By the property of forming *alum*, a double salt, with sulphate of alumina, which crystallizes readily in regular octahedrons. All that is necessary is to pour into a saturated solution of a potash salt, a saturated solution of sulphate of alumina, and to agitate the mixture, when a crystalline precipitate of alum will be formed. 3. By the property of forming, with tartaric acid, a bitartrate of potash, but little soluble in water; so that if we form a solution of tartaric acid into a moderately strong solution of a salt of potash, a white crystalline precipitate of cream of tartar is formed. 4. By the property of giving with chloride of platinum, under similar circumstances, a crystalline yellow precipitate, which is a double salt of chloride of platinum and chloride of potassium. 5. By forming slightly soluble precipitates when perchloric acid and hydrofluosilicic

(1) We take this opportunity of stating that since the date of Messrs. Dixon's letter, as quoted under PHOSPHORUS, p. 392, *note*, those gentlemen have resumed their attempts to employ amorphous instead of common phosphorus in the composition of the paste used for tipping the matches. These attempts have been attended with such success as to lead to the hope that in the course of a few months the public will be supplied with amorphous phosphorus matches. A box of these matches has lately been forwarded to the Editor, and he is happy to be able to report favourably of them. They ignite with moderate friction; they have no smell, and they produce no light in the dark under 400°; they are not liable to contract damp, and may be placed on a hot mantel-shelf without taking fire. It is earnestly to be hoped that the use of common phosphorus may soon be superseded by the amorphous kind, in order to exterminate a cruel disease among the operatives, and to introduce a safer and better article into general domestic use.

acid are added to a potash salt. 6. By colouring purple or violet the outer flame of the blow-pipe.

POTATO. The potato (*Solanum tuberosum*) consists of water, starch, gum, albumen, and lignin. According to the analysis of several kinds, the water varies from 73 to 81·3 per cent.; the starch, from 9·1 to 15·2; the gum, from 1·7 to 4·1; the albumen, from 0·7 to 1·9; and the lignin, from 5·2 to 8·8. The quantity of solid matter varies with the state of ripeness of the tuber; the ripest lose from 68 to 70 per cent. in drying. Those potatoes keep best in which the starch is most abundant; but the starch diminishes by keeping, and probably passes into gum and sugar. The proportion of albumen also diminishes. The cause of the potato *disease*, as it is termed, has not been explained by the researches either of the chemist or the botanist.

POTTERY AND PORCELAIN. The term pottery, derived from *potum*, a drinking vessel, is applied to all ware of the opaque kind; while porcelain, a word of doubtful origin, applies to that which is translucent.

SECTION I.—HISTORICAL NOTICE.

The art of making *pottery*, or vessels of baked earth, is so ancient and so universal that we seek in vain for any precise information as to its origin. It is alluded to in that most ancient record, the book of Job, and is also repeatedly mentioned in other parts of the Scriptures. The potters of Samos were celebrated in the time of Homer; and great quantities of pottery have been found in Egyptian tombs, which, to all appearance, have lain unopened since the time of the Pharaohs. The earliest use of pottery was doubtless that of ordinary drinking vessels; but there was also a religious employment assigned to earthen vessels, which has been the means of preserving them for the inspection of after generations. In vases of baked earth the ashes of the dead were frequently deposited, and even where the practice of burning the dead was not followed, still various earthen vessels have been found placed at the head and feet of the skeleton, and sometimes hanging on pegs along the sides of the tomb. Thus among many distant nations, having different languages, manners, and superstitions, pottery was considered a necessary part of the furniture of tombs.

The potter's art is extremely valuable in an antiquarian point of view. While metal is liable to corrosion, and wood to decay, pottery remains almost unalterable, and has thus been the means of discovering to later ages many points respecting the history, religion, customs, and manners of the ancients, which must otherwise have remained unknown. The potter's art is represented in all its stages on the tombs of Thebes. The mixing of the clay was effected by kneading with the feet; after which a mass of convenient size was formed with the hand, and placed on a wheel of very simple construction, and turned with the hand. During its revolution the forms of the vessel were made out with the finger; the handles were afterwards affixed; the objects were placed on planks to dry, then carefully arranged in trays, and carried to the oven. Ornamental designs were traced with a wooden or metal instrument previous to the baking.

There is a general agreement in the nature and uses of ancient pottery, but at the same time a distinctive character belonging to each country and nation. In this distinctive character consists the value of pottery in an historical point of view. The rude and simple urns of the early inhabitants of these islands; the more carefully fashioned pottery of the Romans with which our country abounds; the simple unglazed earthenware of ancient Greece; the more elaborate forms called Etruscan, of which the finest specimens are, however, attributed to the Greek potters of the Isle of Samos, so celebrated for the delicacy and perfection of their workmanship; the red and black potteries of India; the black and white potteries of North America, the latter interspersed with fragments of bivalve shells; the irregularly formed and fanciful pottery of South America;—all these possess a distinct individuality which makes them clearly recognisable by the student of this interesting art, while it reveals many valuable facts, taken in connexion with the localities in which they are found, their greater or less simplicity, their modes of ornamentation, and the relics which they frequently enclose. On the discovery of the extraordinary ruins of Mitla and Palenque, in Mexico, not many years ago, numerous specimens of pottery were met with, of a remarkably advanced kind for the period assigned to those ruins, namely, one thousand years before the Christian era. These potteries, although made without the turning lathe, are ornamented in different colours, well baked, and covered with a fine vitreous glaze, such as was unknown to Europeans until about ten centuries ago.

As other branches of art advanced, so the potter's art became more and more developed, until at last a very fine hard description of pottery, thin and translucent, was invented and manufactured under the name of *porcelain*, a word, according to some, derived from *porcellana*, the Portuguese for a drinking-cup; according to others, from the Italian word *porcellana*, a univalve shell, of the genus *cypræidæ* or *cowries*, having a high arched back like that of the hog (*porco*, Ital.), and remarkable for a white, smooth, vitreous glossiness of surface. This is the more probable derivation, since there is abundant evidence that the word *porcelain* existed in the French language in the fourteenth century, and consequently anterior to the introduction of Chinese porcelain into Europe.

Porcelain is of comparatively recent origin in Europe, yet it was commonly known in China more than a century before the Christian era. It was not until four or five centuries after that period, however, that fine materials were employed, and that some degree of perfection was attained. Still, taking the later date, the porcelain of China has a high antiquity, and must have been made at least 1250 years before our English porcelain. When the Chinese had acquired a certain amount of skill and perfection

they appear to have rested entirely satisfied with the results, and to have continued producing them without variation for ages. So exclusively were the Chinese the manufacturers of porcelain, that it acquired the name of their land, and became universally known (on its introduction to Europe in 1518) as *China*. For a long period it was also erroneously supposed that the fine clay necessary for the production of good porcelain, consisting of silica and alumina in variable proportions, and called by the Chinese *kaolin*, was peculiar to their land, and that consequently no country in Europe could hope to attain eminence in this manufacture.

Yet the beauty of china led to many attempts at its imitation; success, however, was slow to attend them, for it was not until nearly 200 years from the above date that pure white porcelain began to be manufactured in Europe. Saxony was the birth-place of this manufacture, and Frederic Böttger, or Böttcher, the successful potter. This individual, originally an apothecary's apprentice, and long engaged in the vain endeavour to transmute the baser metals into gold, had also laboured hard to discover the method of making china, but could only produce a sort of red ware, which was much admired at the time, but was greatly inferior to porcelain. While engaged in the search for a better material for his ware, it happened that a merchant named Schnorr, being on a journey, was struck with the appearance of a white-looking earth near Schneeburg, and collected some of it, thinking it might be used instead of wheaten flour in the manufacture of hair-powder. In this idea he was not mistaken, the only drawback being that the wigs dressed with the new hair-powder were very heavy. Böttger noticed the increased weight of his wig, and no sooner discovered that the new powder was earthy in its character than he saw in it at once the long-sought material for porcelain: and on trial it proved that he could make with this substance (long afterwards known as Schnorr's white earth) a porcelain as white as that of China.

The manufacture of Dresden china thus commenced, about 1709-1710, under the direction of Böttger, was carried on with the greatest secresy, and the exportation of the earth was forbidden under heavy penalties. The manufactory itself is at Meissen, near Dresden, and although at this day strangers are permitted to visit it, (the Editor has shared in the privilege,) yet at the time of which we now speak it was treated precisely as a stronghold, the drawbridge was only lowered by night, and the work-people were sworn to observe "Secresy to the Grave," this being the motto affixed to the doors of the workshops, and kept constantly before their eyes.

So completely successful was Böttger in his attempts to imitate the porcelain of China, that the most experienced eye can scarcely detect the difference in colour, form, painting, or gilding between his works, still exhibited in Dresden, and those of the Chinese. For about thirty years the secret was kept, but gradually the work-people were won from their allegiance, and sold their skill and knowledge to other masters. Thus the manufacture spread to Vienna, Munich, &c., and porcelain works were established in several states of Germany. Great efforts were made in France to promote a similar manufacture, and a factitious paste was introduced consisting (it is said) of nitre, sea salt, alum, soda, gypsum, and sand, reduced to a frit and mixed with one-third its own weight of chalk, and calcareous marl. Of this a porcelain was manufactured, since known by the title of *tender* porcelain, to distinguish it from the hard porcelain of Dresden and of China. This was fabricated at much cost and trouble, and was brilliant and highly susceptible of ornament. In turning this description of porcelain a saline and siliceous dust was produced, very injurious to the workmen, and productive of asthma and consumption. The term *tender* does not imply softness, but is meant to express two qualities of this ware, viz. that the paste is fusible at a lower temperature than that at which the hard porcelain is baked; and the glaze is capable of being scratched with a steel point. This tender porcelain was altogether different from the soft porcelain of the present day.

The endeavours to imitate the porcelain of Dresden and China were continued in France, and were greatly furthered by the discovery, in 1768, of an abundant supply of fine porcelain earth in a ravine at St. Yrieix, near Limoges. The wife of a surgeon had collected some of it for the purpose of bleaching linen, when her husband, suspecting its real value, took it to Bordeaux, and on trial it was found to be the very thing needed as a base to the real hard porcelain. The manufactory of Sèvres, already celebrated, acquired from this time an increased renown for the hardness as well as extreme beauty of its porcelain. M. Alexandre Brongniart became director of this manufactory in 1800, and to him we are indebted for the best and most interesting of works on the ceramic art.[1] The art of making glazes for the finer descriptions of pottery had been greatly advanced in France during the sixteenth century by Bernard de Palissy, a remarkable man, who acquired fame and fortune by his discoveries, and yet cheerfully closed his life in prison, rather than deny Protestant truth, or bend the knee before the images which he had made. In the early English porcelain, a fine sand brought from Alum Bay, in the Isle of Wight, was mixed with plastic clay and powdered flint glass, and covered with a leaden glaze. This manufacture was carried on at Chelsea, and had considerable success. In 1748 it was transferred to Derby. The Worcester Porcelain Company (which still exists) was established in 1751, and to its originator, Dr. Wall, is ascribed the invention of printing on porcelain by transferring printed patterns on paper to the biscuit. A few years later the manufacture of porcelain commenced in Staffordshire. In 1800 Mr. Spode manufactured a porcelain in imitation of the ancient tender porcelain of Sèvres, and introduced calcined

(1) "Traité des Arts Céramiques ou des Poteries, considérées dans leur Histoire, leur Pratique, et leur Théorie." In 2 vols. 8vo. with an Atlas of plates; Paris, 1844.

bones in the paste. His establishment, now in other hands, still constitutes one of our most extensive porcelain works. Notwithstanding all these efforts, however, the porcelain manufacture in England was less successful than that of the finer kinds of earthenware. These were fabricated in great beauty and perfection by Josiah Wedgwood, whose ware was much esteemed for its excellent workmanship and its cheapness. The same qualities still bring celebrity to the manufactures carried on in Staffordshire, where an extensive district embracing many towns and villages is known throughout the kingdom under the title of the Potteries. One of these villages was built by Wedgwood, and called Etruria. The first important step in the improvement of the ordinary potter's work carried on in this district, was made about 1790, when two brothers named Elers arrived from Holland, and brought certain secrets of the trade, which for a time were closely kept, until one Astbury, feigning to be of weak mind, obtained access to their works, and discovered their processes. To this man is ascribed the introduction of calcined flints in the composition of cheap stone-ware. This was an important discovery, and paved the way for the perfection afterwards attained by Wedgwood. The principal inventions of Wedgwood were a beautiful kind of table ware, called, by royal command, *Queen's ware;* a *terra cotta,* which could be made to resemble porphyry, granite, &c.; *basalts,* or black ware, which would strike sparks like a flint; *white porcelain biscuit,* with properties similar to the basalt; *bamboo,* or cane-coloured biscuit; *jasper,* a white biscuit of exquisite delicacy and beauty, fit for cameos, portraits, &c.; and a *porcelain biscuit* little inferior to agate in hardness, and used for mortars in the laboratories of chemists.

The value of Wedgwood's discoveries is fully appreciated by eminent French manufacturers. A French authority confesses that the English surpass all other nations in the fabrication of a stone-ware remarkable for lightness, strength, and elegance, and also in printing blue figures upon it of every tint by processes of singular facility and promptitude. Another French authority truly states that the excellent workmanship of the English ware, its fine glaze, impenetrable to acids, its beauty, cheapness and convenience, have given rise to a commerce so active and so universal, that in travelling from Paris to St. Petersburg, from Amsterdam to the furthest part of Sweden, or from Dunkirk to the extremity of the South of France, one is served at every inn upon English ware. Spain, Portugal, and Italy are supplied with it, and vessels are laden with it for both the Indies, and the continent of America.

The annual production of the English potteries is now estimated at no less than 2,000,000*l.*; 185 factories being engaged in this branch of labour: 52 are scattered over the country at Leeds, Stockton, Sunderland, Glasgow, Bristol, Swansea, &c., and 133 are in North Staffordshire, where 60,000 persons are employed in the "Potteries." Last year 84,000,000 pieces were sent out, representing a value of 1,122,000*l.* This exportation (except in a small number of countries where English pottery is prohibited or submitted to heavy duties) is scattered over the entire world. A very limited number of countries can supply themselves with earthenware or china—those precisely in which the arts and sciences are most advanced. The immense continent of America has not produced to this day anything of the kind worth mentioning; and if we put aside the Chinese, we shall not find more than three nations who can export pottery to any extent. England first, then France, then Germany; but the last to a much smaller extent.

In 1768 certain mineral substances were found in Cornwall, possessing similar properties to the porcelain earths of China, [see CLAY,] and this led to the manufacture of a superior quality of porcelain. Very beautiful productions are now obtained in the various British porcelain works, yet these, with few exceptions, do not admit of being classed with true hard porcelain. They are baked at a much lower temperature than the German or Oriental porcelain, are produced on an extensive scale, and at moderate cost. To quote a recent writer on this subject, "The English porcelain may be considered as holding a place intermediate between the hard porcelain of China and Germany, and fine stone-ware. It is distinguished from the first by the paste being more friable, and by its plumbiferous glaze; and from the second by its transparency and its stronger glaze." These remarks, however, do not apply to the excellent hard porcelain for chemical purposes manufactured by the Messrs. Minton, for the first time in 1850.

In concluding this outline of the history of pottery and porcelain, we must refer to the collections which have been formed from time to time by private individuals in this country; and also to the valuable national collections at Dresden, Sèvres, &c., to which the student should repair (if opportunity offers) for instruction. One of the richest and most remarkable of private collections is that of the Duke of Hamilton, which includes a portion of the rare and curious pieces once exhibited at Fonthill Abbey, with a miscellaneous collection of extraordinary interest. The Earl of Harewood possesses a most important collection of Sèvres china, the greater part of which was formed by his uncle (known as Beau Lascelles); so also does the Earl of Lonsdale. Sèvres china has also been largely collected by the Hon. John Ashley, R. Bernal, Esq., C. Baring Wall, Esq., and numerous other admirers of the ceramic art. A list of collectors before us reaches to nearly one hundred,[1] and we have good authority for saying that this number might be doubled, so extensive is the taste for making collections of pottery and porcelain. It is interesting to observe, that individual collectors have had their peculiar tastes for different kinds of ware; and thus no doubt the history of the art has been served, by a more extended research after the

(1) "Collections towards a History of Pottery and Porcelain in the 15th, 16th, 17th, and 18th Centuries," by Joseph Marryat. 8vo. London, 1850.

manufactures of particular persons or periods. While the china of Sèvres and Dresden is in favour with the majority of collectors, there are also collections in which the less known wares figure prominently. Thus the Duke of Norfolk, the Hon. Sidney Herbert, Lord Hastings, and others, have collected the ware known as Majolica; I. K. Brunel, Esq. has turned his attention to Palissy ware; Lady Stafford has collected ancient pottery; the Earls of Warwick and Harrington, and Sir A. de Rothschild are among those who have studied faïence; the Duke of Marlborough's collection is chiefly oriental; Lee Jortin, Esq. has a collection of the ware named after Luca della Robbia; and so on. The English manufacture of former days is also recorded in such collections of Chelsea ware as those made by the Earls of Cadogan and Enniskillen; of Worcester ware by the Earl of Glengall; of Wedgwood ware by T. de la Rue, Esq.

The earliest in celebrity among national collections of porcelain is that of the Japanese Palace at Dresden. This was founded by the Elector Frederick Augustus I., who purchased the building and enriched it with a quantity of oriental porcelain obtained from Holland, and whose love of porcelain carried him so far, that he exchanged his finest regiment of dragoons with Frederick William of Prussia, for about two dozen large vases. His son, possessing a similar taste for the ceramic art, arranged and added to the magnificent collection. It is now one of the well-known objects of interest in the Saxon capital, and although the Editor, for his own part, must confess to the fact of finding the assemblage more curious than beautiful, yet it is undoubtedly one of great importance in a national point of view. The oriental china alone occupies thirteen rooms, beginning with the unglazed red ware of Japan, ornamented in red, white, and black, and richly gilded, and proceeding to some rare and valuable vases in all shades of blue, as well as buff and brown, arranged in what is called "the Blue Gallery." Then there are no less than eighty-two large vases, with green, black, red, and blue ornaments on a white ground. There are also strange and eccentric subjects and monstrous figures in porcelain, painted and enamelled ware, snake-porcelain, and white ware in immense variety, the last named being fabricated in such unexpected forms as figures of deities, lions, cows, elephants, &c. There are also specimens of the Dresden manufacture from its infancy to its ultimate perfection, and these would have been much more complete had not political disturbances at various periods diminished the treasures of the Japan Palace. As it is, the Curator of the Museum justly directs attention to it as a most instructive part of the exhibition. "In the room called Böttcher's room," he says, "there are specimens of the ancient porcelain, executed previously to 1763, made of the clay found at Meissen, red without glaze; the red polished by lapidaries; the red glazed; the iron-grey without polish or glaze; the black glazed, in imitation of the Chinese; the earliest blue and white, in imitation of the Nankin; then the first white porcelain—the same painted with colours; flower vases and groups of Cupids, and other exquisite productions; figures by Kändler; also by the same artist two leopards of natural size, a colossal bust of Augustus II., a concert of apes, sixteen admirable figures, and various others of the same description."

The Museum at Sèvres contains a collection of a very different kind from that of Dresden: its nature and objects have been explained in a costly and beautiful work, the title of which is given below.[1] It is a splendid collection, and is intended to illustrate the potter's art, and to reveal to the student all that has been done up to the present day. The collection was not made with a view to the study of beautiful forms nor to the study of history or archæology; but it was made in order to illustrate in the completest possible manner the history of the ceramic art. The periods when certain pastes or glazes were introduced, and the form of the vessel, its inscriptions and decorations, were only applied to the determination of the state of the art among such a people and at such a time. Bearing in mind the precise object of this museum, we should prefer, say the authors, "to possess a Greek, Roman, Etruscan or Mexican vase with certain defects which revealed to us the principles of its fabrication, to a vase with inscriptions or ornaments capable of being turned to most instructive use in illustrating the history of the people who produced it."

It was not until the year 1812 that the museum was arranged on its present basis by M. Brongniart. At that period the collection of the establishment consisted,—1. Of the rich and interesting collection of Greek vases procured by Louis XVI. about 1785, to serve as models of simple and pure forms, and to correct the bad taste into which the modellers had fallen during the preceding reign; 2. Specimens of porcelain from the works of Meissen, Berlin, Brunswick, Wurtemburg, Vienna, &c.; 3. Specimens from various parts of France, collected in consequence of a request on the part of government that experiments should be made at Sèvres on the composition of coarse pottery and its glazes, with a view to its improvement. It was determined, in arranging this somewhat heterogeneous collection, to distribute it so as to illustrate, 1. The progress of the ceramic art from the manufacture of a brick up to a piece of porcelain; 2. The geography of the art, or specimens of the art as practised among all nations; 3. The chronology of the art from the most distant periods to the present time.

The objects in view thus clearly defined were made public, and were carried out with so much success, that in the course of 30 years the present most instructive collection was brought together, either by purchase of certain specimens, the exchanging of duplicates or other forms of barter, but chiefly by means of free contributions. In arranging the collection, it was made a condition that every article,

(1) Description Méthodique du Musée Céramique de la Manufacture Royale de Porcelaine de Sèvres, par M.M. A. Brongniart, Administrateur, et D. Riocreux, Conservateur des Collections. Fol. Paris, 1845; with 80 coloured lithographic plates.

every specimen of clay, silica or other material should have a label written in oil colour containing concise but sufficient particulars respecting it, and no article was admitted until its appropriate label was prepared. In this way articles of no value whatever without their labels, became invested with a high degree of technical interest when the name, the composition, the origin, the locality, the date, the use, &c., were attached to them.

To the evident utility of the collection thus arranged M. Brongniart attributes its rapid increase and success: about seven-eighths of the whole collection was presented by different individuals, among whom captains in the French navy are conspicuous. On their return from distant parts they were proud to be able to present to this valuable museum some specimen of pottery illustrative of the art as practised in a remote corner of the globe. Our English manufacturers have also contributed most liberally to this collection, and while reading with pleasure M. Brongniart's candid and graceful acknowledgment of their liberality, we could not repress the feeling of regret that Great Britain does not possess a similar collection.

The collection of raw materials used in the art is very large and complete. It is not open to the public, nor is it perhaps sufficiently attractive for the purpose; but any student can gain access to it on proper application. These specimens, furnished with permanent labels, are arranged in drawers, above which are cases containing the finished articles. They are not classed according to their mineralogical, nor even their technical, characters, but with special reference to the manufacture to which they pertain. In this part of the museum is a collection of tools, implements, trial pieces, and articles which have a purely historical interest, illustrating the progress of the art. Thus there is the *first* article that was made with kaolin after its discovery at Saint Yrieix in 1765. There is also a collection of drawings and plans of ovens, utensils, &c., used in different parts of Europe.

The chronological arrangement of the specimens of pottery and porcelain illustrates in a remarkable way the progress of taste or the prevailing fashion. Thus in accompanying artists and educated persons through the museum, M. Brongniart thus refers to his own experience:—"Between the years 1800 and 1815 persons of taste regarded as being beneath their notice, below criticism, all the specimens of the art which were produced between 1740 and 1790. Taste then suddenly took a different direction, and attached itself to Greek forms, with more or less success according to the merit of the artists who adopted them. In 1815 there was again a sudden and violent change. All these forms, all these groups, which but a few years before had been regarded with such disgust that I was compelled to pass as rapidly as possible before the cases which contained them, to escape from the odious criticisms which were poured upon them,—these same specimens now excited the highest admiration, and were eagerly sought after by all who pretended to taste or who professed it, such as artists of distinction."

There is yet another department of this interesting museum, viz. a collection of *failures!* It was a favourite remark of John Hunter, that the art of surgery would not advance until professional men had the courage to publish their failures as well as their successes. We believe that this has been done with much of the success that was anticipated. At Sèvres specimens are preserved of raw materials with the dated results of experiments upon them; finished articles showing the application of the data furnished by these experiments, either in success or failure; and secondly, specimens illustrating the methods adopted to overcome the defects thus exhibited. The peculiar value of such permanent records of failure as well as success is self-evident—it marks the progress of improvement and anticipates retrogression by showing what has been done and what it is hopeless to attempt.

Regarding this museum as a whole, we quite agree with M. Brongniart that it is eminently calculated to illustrate the progress of the art. Scientific collections have, or ought to have, a higher object than merely to excite the curiosity and admiration of an uninstructed public. Without neglecting the appeal to the sense of the beautiful, the gratification of that sense may be heightened indefinitely by combining with it the useful and the instructive. It is of little importance to speak of *progress* in an art, unless that progress is illustrated and rendered evident to the eye. Books devoted to the subject do this very imperfectly. The introduction of chromium into the procelain manufacture, of uranium into stained glass, &c., may be recorded in books on chemistry, but even the manufacturer can have little or no idea of the effects, except by the costly method of actual trial, or by the inexpensive mode of inspecting the specimens preserved in permanent and well arranged museums; and it is only by the latter method that he can make a practical study of his art as practised in different ages and climes. At the museum of Sèvres the potter may in a few hours gain a precise idea of his art as practised in the sixteenth century in China, Germany, Flanders, &c., and then see how it is practised in his own day in the same and in other countries. We again ask, Why are not similar facilities furnished to the English potter? The answer probably may be, that we have no Royal Porcelain-works, and that we are accustomed to perform by private enterprise many things which on the Continent are undertaken by Governments. There is also probably a feeling of pride which prevents us from *imitating* the example of other nations. We prefer to do things in our own way; and although they may "do these things better in France," yet it may be a question whether it would not be more in accordance with our national habits to leave the conduct of industrial education to our great manufacturers, than to attempt to force upon the people institutions for which they are not adapted. We should be sorry to slight the attempts which are now being made to promote

industrial education. We rejoice that increased facilities for study are being afforded. Schools of design, museums and courses of lectures are valuable *aids* to study; if the people seek them with eagerness and rapidly improve in them, the value of such institutions will be demonstrated, and they will succeed, and gradually adapt themselves to the wants of the people and of the age. Our museums are at present splendid examples of heterogeneousness, in which the student is confused by the multitude of objects before him, where the want of unity of purpose in the collection is opposed to concentration of thought in the student. The Museum of the School of Mines is not free from this objection; although it has the great merit of system, yet that system is too large, its scope too wide. The Museum of Sèvres appears to us to be a perfect model of what this kind of institution ought to be, and it might, if the will only were present, be carried out on a magnificent scale in the manufacturing towns of Great Britain, each town forming its own museum to illustrate the branch of art or manufacture for which the town itself or the neighbourhood is celebrated. Manchester might collect into a historical series the various machines that have been employed in the manufacture of cotton, and also furnish specimens illustrative of the habits and culture of the cotton plant. Sheffield would be the representative of steel; the Potteries, of the ceramic art; and so on. If each museum were served by competent men, lectures given and a journal published, the particular branch of manufacture thus illustrated would always be in advance. Each museum would form a sort of focus in which converging rays of knowledge from all parts of the world would meet in order to diverge and diffuse the light of intelligence around. That such a plan will ever be carried out in this country is not likely. The Great Exhibition contained the rich germs of a large number of industrial museums, and we scattered to the winds that noble collection, the most useful parts of which might so easily have been retained. No; we prefer to do things in our own way. We educate our people to build steam-engines and to expend power in vast mechanical enterprises; we keep the hand of labour busily employed during six days of the week, night and day, and grudge the seventh day's rest; there is little national feeling for a national education of a higher kind: if we want taste, we send to Paris or Italy to purchase it; and if the artist does not supply us fast enough in his own country, we purchase the artist himself, and he becomes an integral portion of the factory.

Section II.—Materials employed—Divison of the Subject.

The ceramic [1] art, in its widest sense, includes the preparation of all articles in clay or argillaceous matters, which are submitted to the action of fire; so that a comprehensive treatise on the subject would include the manufacture of bricks and tiles, as well as of the choicest specimens of pottery and porcelain.

The essential ingredients in every kind of clay, and, consequently, in every article in pottery and porcelain, are silica and alumina. [See Clay.] The pure compound *silicate of alumina* is, it is true, an ideal type; since no clay, or artificially prepared pottery or porcelain paste, is ever free from admixture with other ingredients, such as iron, lime, potash, &c. If, however, we remove from the paste either the silica or the alumina, we render it useless for the purposes of the potter; but by purging the paste of the accidental ingredients, the iron, lime, &c., we exalt those properties which render it fit for the preparation of fictile articles. An intimate mixture of silica and alumina with water acquires, by exposure to a high temperature, the required degrees of hardness and density; but for many purposes it is necessary to impart a certain degree of fusibility, to which end other substances are used in various proportions, capable of forming vitrifiable double silicates with alumina and silica. These substances, diffused through the paste formed by the simple silicate of alumina, in some cases with silica in excess, in others with excess of alumina, greatly contribute to the cohesion and hardness of the mass.

The various mixtures employed in the different branches of the manufacture, have been thus classified by M. Dumas:—

Silica, alumina	Ideal type.
Silica, alumina, lime	Earthenwares, crucibles, bricks, tiles, encaustic tiles and common pottery.
Silica, alumina, oxide of iron	(same)
Silica, alumina, lime, oxide of iron	(same)
Silica, alumina, potash	Hard porcelain.
Silica, alumina, soda	Soft porcelain.
Silica, alumina, magnesia	Piedmont porcelain.
Silica, alumina, baryta	Stoneware.

The terms *soft* and *hard* as applied to Pottery, or, as the French name them, *tendre* and *dur*, have reference, not only to the composition, but also to the degree of heat to which the ware is exposed in the furnace. Thus common brick is soft, fine brick is hard. Common earthenware vessels, such as pipkins, flower-pots, &c., are soft; while crockery, such as Queen's ware and stone ware, is hard. Soft pottery, named by the French, *fayence* [2] *à pâte tendre*, is the most ancient. Soft pottery, composed of silica, alumina, and lime, is generally fusible at the heat at which porcelain is baked. It can be scratched with a knife or file. Four kinds of pottery are distinguished by collectors, viz.—1. the *unglazed*, 2. the *lustrous*, 3. the *glazed*, and 4 the *enamelled*. The first three comprise the ancient pottery of Egypt, Greece, and Rome, as well as the more modern in common use among all nations. The enamelled is covered with a thick vitreous enamel, capable of being ornamented with paintings of great delicacy and beauty. The *Majolica*, or enamelled pottery of Italy, is of this kind.

(1) Κέραμος, *potter's clay*, supposed by some to be derived from κεράννυμι, *to mix up*. Others derive it from κέρας, an animal's *horn*, used as a drinking-cup. Others, again, suppose it to be from ἔρα, *earth*.

(2) The word *fayence*, or *faience*, is an old French term for all descriptions of glazed earthenware, even including porcelain. It corresponds in general use to the English word, *crockery*.

The terms *hard* and *soft* are also applied to PORCELAIN, and they may be distinguished by applying the point of a knife, which will scratch the soft, but will make no impression on the hard. The hard kind contains a greater portion of alumina, and less silica; it is exposed to a greater heat, and has a greater density than the soft. Soft porcelain contains a larger proportion of silica, together with alkaline fluxes; it bears a less heat, and is less dense than the hard. It is, in fact, soft in two senses, in being less able to resist a high temperature, and in being easily scratched by a knife. Réaumur endeavoured to produce porcelain by means of hardening and giving opacity to glass. [See GLASS, Sec. II.] Böttcher succeeded in making hard porcelain, by softening pottery, and rendering it translucent. In fact, porcelain may be considered as a substance intermediate between pottery and glass.

After the article formed in clay has passed through the fire it becomes converted into a porous substance termed *biscuit*, and it is rendered impermeable to water and durable under wear by means of *glazing* or *glassing*, *i. e.* covering the surfaces of the biscuit with a thin layer of glass. For fine wares, such as porcelain, the vitreous glaze has a close analogy to the substance of the paste itself; it is not very fusible, but yet must melt at a lower temperature than the article which it is destined to cover and protect. The glaze incorporates itself so completely with the biscuit, that on breaking a piece of well-prepared porcelain it is impossible to mark the line of separation between the biscuit and the glaze. A very high temperature is required to produce this effect. The glazes for pottery are much more fusible.

The materials for porcelain are selected and prepared with so much care that the biscuit, on leaving the kiln, is colourless: the glazes also are selected of such materials as will form a pure transparent glass. The clays which are used for pottery-ware being impure, and frequently containing protoxide of iron, the latter is converted, by the oxidizing influence of the flame, into a peroxide, which colours the clay red. This red colour of the biscuit is concealed by an opaque glaze, or by communicating a deep colour to transparent glazes. The pottery glazes do not combine with the biscuit, but form a distinct layer on its surface. Coarse potteries are glazed on one firing only, for which purpose, while they are at a very high temperature, a quantity of moist salt (chloride of sodium) is thrown into the kiln: the salt is volatilized and decomposed in the presence of moisture, and in contact with the heated surfaces of the clay: hydrochloric acid is disengaged, and the articles become covered with silicate of soda, which, combining with the silicate of alumina (the clay), forms a very fusible double alkaline silicate or glaze on the surface of the articles.

It is remarkable that nearly all the products of the potter's art have, in all ages, and among all people, been deemed incomplete without the addition of an ornament of some kind not required in the use of the article ornamented, but simply for the purpose of pleasing the eye. The very plastic and impressible nature of the material doubtless offers considerable facilities for the purpose, and in many examples of the unglazed pottery of rude nations, in addition to great beauty of form, simple ornaments have been added with exquisite taste; such as straight or flowing lines impressed with a point; equidistant indentations, or elevations; and in proportion as a people becomes refined, the ornaments become more elaborate, if not more beautiful. The ornaments on pottery and porcelain, which depend on colour, are afforded by gold and platinum, or by metallic oxides capable of furnishing coloured silicates unalterable in the fire. In the ornamentation of porcelain the skill of the artist, and the science of the chemist, have been exerted to the utmost; although it may fairly be questioned whether works of high art are properly represented on so fragile a material as porcelain, considering the great difficulties of the art and the large number of precautions required.

In order to lay before the reader as full an account of the theory and practice of the ceramic art as our limits will allow, we propose to follow an upward course, commencing with the preparation of articles in which the crude material undergoes very little preparation, until we arrive at the finer kinds of ware, the materials for which are prepared with the greatest care, and the ornamentation and glazing of which require much skill.

SECTION III.—MANUFACTURE OF COARSE POTTERY.

The manufacture of bricks and tiles offers an example of the lowest application of the potter's art We have already devoted an article to the manufacture of bricks, [see BRICK,] and have now to notice the method of making tiles.

The clay used for making tiles is purer and stronger than that employed in brick-making. In order to open the pores of the clay and separate the particles so that it may absorb water and work freely, the clay is exposed to the weather. The *weathering* is performed by spreading it out in thin layers about 2 inches in thickness, and exposing it to at least one night's frost, or to the scorching heat of a summer's sun, before another layer is put on. In very cold or very hot weather the layers may be 4 inches thick. The weathered clay is thrown into pits, and left covered with water for a considerable time, to *mellow* or *ripen*. Before being used it is *tempered* by being passed through the pug-mill. The pug-mill here used differs from that described under BRICK, Fig. 235, for instead of being conical it is made to taper at both ends, and the ejectment hole is at the bottom instead of in the front. If the clay be very foul, or full of stones, it is *slung*; that is, as the clay issues from the pug-mill it is cut into lengths of about 2 feet with a *sling*, or wire-knife, consisting of a piece of wire with two handles, shown in Fig. 1677. The slingers cut up these lumps into slices not above $\frac{3}{4}$ inch thick, during which the stones fall out or are picked out by hand. The clay is then passed again through the pug-mill, and is ready for the moulder. For chimney-

pots and similar articles the clay is slung once or twice, and pugged or *ground*, as it is called, two or three times. In some parts of England the stones are separated from the clay by sifting, and the tempering is done by *treading*, an operation noticed under Iron, Fig. 1426, when describing the mode of making the clay crucibles for cast-steel.

The clay as it issues from the mill the last time is cut into lumps or pieces, which are stacked on a rough bench; these are cut by a labourer into *half-pieces*, and wheeled one by one to the pan-tile table.

We may here remark that tiles are of three classes, viz. *paving* tiles, *roof* tiles, and *drain* tiles. Paving tiles may be considered as thin bricks. Roofing tiles consist of *pantiles*, which are curved so as to form with each other a water-tight joint; and *plaintiles*, which are flat. These were formerly made with holes in them for the reception of the tile pins, by which they were hung on the laths, but it is now usual to turn down a couple of nibs on the head of the tile, which serve instead. Pantiles are moulded flat, and afterwards bent into shape on a mould; as is also the case with *hip*, and *ridge and valley* tiles.

The *pantile table* or *moulding table*, Fig. 1675, is placed under a shed, which also shelters the *blocks* or drying shelves on which the tiles are placed as they are formed. Each shelf is formed with three 1-inch planks placed edge to edge, and separated from each other by bricks placed edgewise; each block

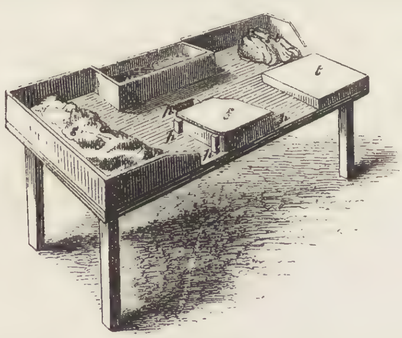


Fig. 1675.

contains about 14 shelves. The moulding table contains a *trug* or trough *c*, into which the moulder dips his hands when moulding, and a *block* and *stock-board* *f*, on which the tile-mould is placed during the moulding. They form one piece, which is keyed to the moulding table by a tenon *t*, Fig. 1676, on the under side of the block passing through a mortice *m* in the table. Four pegs *p p*, Fig. 1675, driven into the table at the corners of the block and stock-board, support the mould and regulate the thickness of the tile, which for a pantile is $\frac{5}{8}$ths of an inch. The tile-mould, sling and wooden roller are shown in Fig. 1677: the process of moulding is thus described by Mr. Dobson:—"A rough moulder, generally a boy, takes the half-piece and squares it up, that is, beats it up into

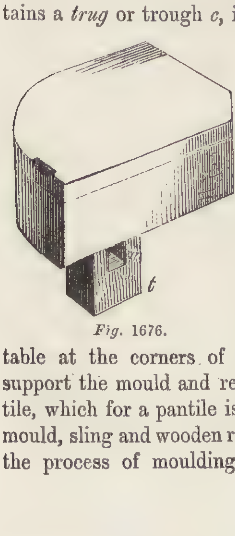


Fig. 1676.

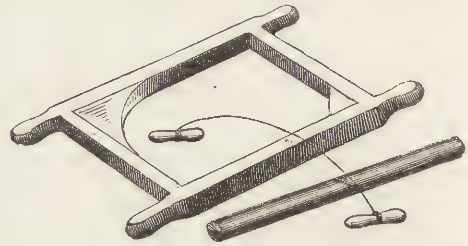


Fig. 1677.

a slab near the shape of the mould and about 4 inches thick, from which he cuts off a thin slice, the size of a tile, and passes it to the moulder. The moulder having sanded his stock-board and placed his mould on the 4 pegs which regulate the thickness of the tile, takes the slice of clay from the rough moulder and puts it upon the mould. He then, with very wet hands, smooths the surface, cutting off the superfluous clay with his hands in long pieces called strippings (*s t*, Fig. 1675,) which are thrown to a corner of the table. This done he stirkes the surface level with the roll; and turning the tile out of the mould on the washing off frame, (*f*, Fig. 1678,) with very wet hands washes it into a curved shape. He then strikes it smartly with the *splayer* *s*, Fig. 1679, and turns it over on that implement, on which he conveys it to the block, where he deposits the tile with

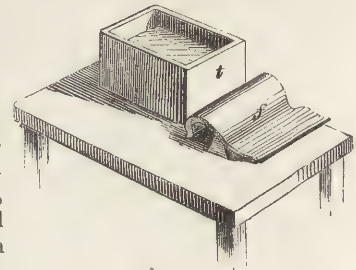
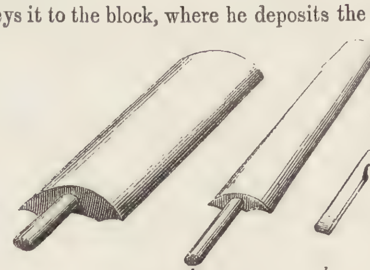


Fig. 1678.



s *t* *k*

Fig. 1679.

the convex side uppermost, and the splayer being withdrawn the tile is left to dry. The button end of the tile is placed inside the block. The tiles remain in the block until they are half dry, when they are taken out one by one, placed on the thwacking frame, Fig. 1680, and beaten with the thwacker *t*, Fig. 1679, to perfect their shape. The wing of each tile is then trimmed with the thwacking knife *k*, Fig. 1679, and the tiles replaced in the block still with the convex side uppermost; but this time the button

(1) "On the Manufacture of Bricks and Tiles," published in Weale's Rudimentary Series.

end is placed outside. The tiles then remain in the block until ready for kilning." The tiles flatten

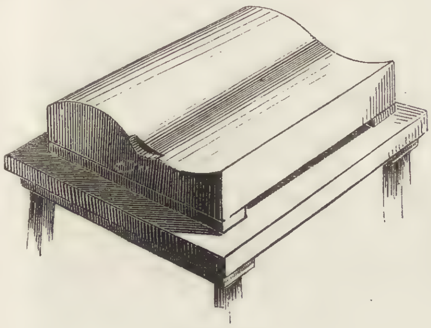


Fig. 1680.

slightly in the block, and hence the washing off frame is made a little more convex than the thwacking frame, the latter corresponding to the permanent form of the tile.

At Basford, in Staffordshire, where there is an extensive hill of good marls, tiles are made in the following manner:—The mould is 12 inches by $7\frac{3}{4}$ inches, and $\frac{1}{2}$ of an inch thick, and is made of oak plated with iron. The moulder at his bench works a lump of clay into an oblong square somewhat less than the mould: the mould M, Fig. 1681, being placed on the bench, fine coal-dust is thrown into it from the box C; the lump of clay is then dashed down into the mould with considerable force, and the surplus clay is cut off level with the mould by means of a brass wire strained upon a wooden bow B; the lump is then removed, and the clay left in the mould finished by adding a little clay if it be wanted, and smoothing it over with a wooden rod. Two thin boards about the size of the moulded tile are dusted over with coal-dust; upon one of these the moulded tile taken out of the mould is placed, the half circular projections extending beyond the board. In this way one man moulds from 1300 to 1500 tiles per day. A boy carries away 2 tiles at a time to the floor; he takes up one on the board, and by the thick part of the hand presses up the two projections at right angles with the face of the tile, and then places the board and tile on his head, and, his hands being thus at liberty, he operates on the second in like manner, while walking to the floor, where he deposits the two tiles, and carries the boards back to the moulding-bench. The tiles are left on the floor about 4 hours: they are then collected and placed close together, the nib end changed alternately, to allow them to rest close and square; in this state they are walled up in a dry situation, and left for a day or two. The *set* or curved form is given to them by means of a *horse* *h*, Fig. 1682, or three-legged stool, the top of which is a little larger than the tile, and is curved one way to about a 10 feet radius. There is also a wooden block *b*, curved to correspond with the surface of the horse. Six tiles *t* are put on this horse, the man then lifts the wooden block, and gives them three sharp blows with it: they are next taken away, and built up with other similar tiles into the kind of wall shown in Fig. 1683, to dry; the courses being separated from each other by laths *ll*, two to each course. After this the tiles are ready for firing.

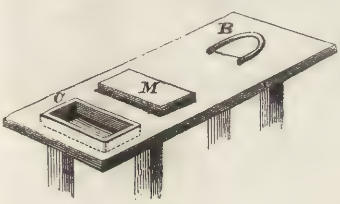


Fig. 1681.

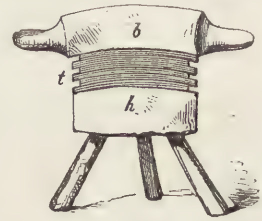


Fig. 1682.

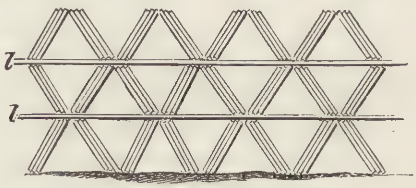


Fig. 1683.

Fig. 1684 is a section of a portion of a London tile-kiln: it has arched furnaces enclosed in a conical building called a *dome*. The whole of the furnace and body of the kiln is of fire-brick, and the arrows mark the direction of the flues. In setting the kiln, a course of vitrified bricks is laid at the bottom, herring-bone fashion, $1\frac{1}{2}$ inches apart. On this course the tiles are stacked as closely as they will lie, in an upright position, one course above another. As the body of the kiln is filled, the hatchways are bricked up with old bricks, and when the kiln is topped, they are plastered over with loam or clay. The top is then covered with a course of unburnt tiles, placed flat, and lastly with a course of old pantiles loosely laid. The fires are lighted on Monday

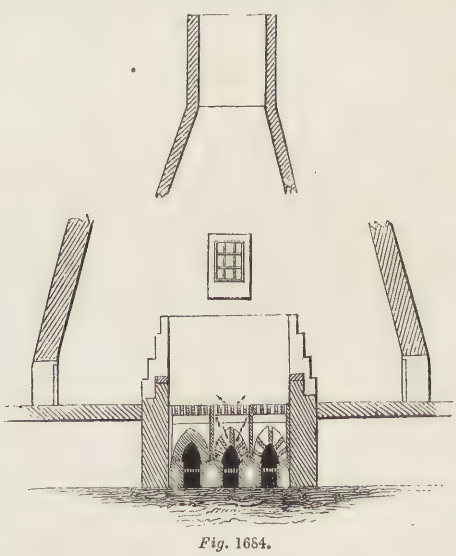


Fig. 1684.

morning, and not put out until Saturday night. About 8 tons of coal are consumed at each burning.

The London tileries also make drain-tiles, drain-pipes, chimney-pots, garden-pots, and various other articles. The large and increasing demand for draining tiles and pipes, has led to great economy in their manufacture. Some are moulded flat, and afterwards bent round a wooden core to the proper shape: others are made at once of a curved form by forcing the clay through a *dod* or mould, Fig. 1685, by mechanical pressure. The action will be readily understood from Fig. 1686, which represents a section of a strong iron cylinder, containing a quantity of clay in the act of being pressed down with enormous force by a solid piston or plunger. The clay as it escapes through the dod is evidently moulded into the form of the pipe, (also shown in section,) which is cut off in lengths, by means of a wire, and these, after a preliminary drying, are ready for firing. By using dods of different sizes, pipes of various magnitudes are formed.

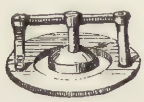


Fig. 1685.

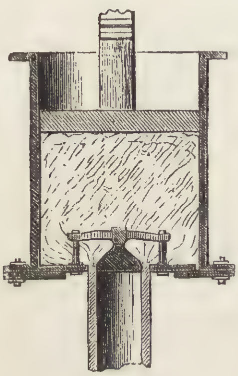


Fig. 1686.

Fig. 1687 is an elevation of a drain-pipe making machine, which we have copied from Mr. Green's works at Lambeth. The cylinder contains a second cylinder, capable of holding a given weight of clay, adapted to the moulding of a certain number of pipes at one charge. Thus, one *box-full* will furnish five 9-inch pipes, six 6-inch pipes, seven 4-inch pipes, and so on. By the action of the rack the piston forces the clay through the dod or die upon a table, so balanced by weights that the lengthening pipe is sufficient by its weight to force down the table, and when a certain length of pipe is formed, the boy stops the machine by shifting the strap which drives the rack-screw from the fast to the loose pulley, and then cuts off the length of pipe with a wire, removes the pipe so formed, raises up the table, sets the machine in action, and receives a pipe upon the table as before. When all the clay is thus forced out of the cylinder, the action of the rack is reversed, whereby the plunger is drawn up out of the cylinder. The cylinder, which moves on a kind of hinge, is then tilted on one side to receive its charge of clay, and being restored to its vertical position, the action proceeds as before. By an ingenious contrivance, the fork which shifts the strap from the fast to the loose pulley is weighted in such a manner that when the boy raises his foot from a treadle, the strap is at once moved on to the loose pulley, and *vice versâ*, thus giving the attendant a third hand, and diminishing the chances of danger from the strap. Mr. Green has a machine worked by a screw, in which the process is continuous. These pipes are washed with glaze before the firing, as will be explained hereafter.

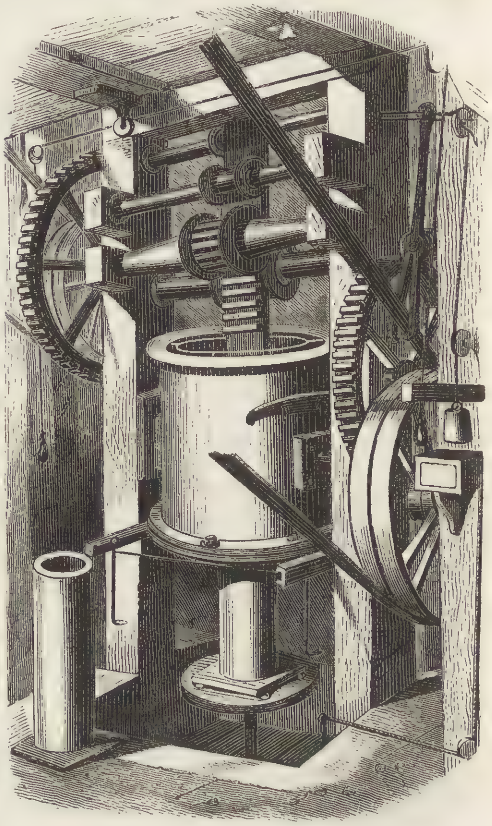


Fig. 1687. DRAIN-PIPE MAKING MACHINE.

By means of a tile-machine, the *hollow bricks* are formed, which are so much recommended by the "Society for Improving the Condition of the Labouring Classes," and introduced by them in the construction of dwelling-houses for the poor. The idea of tubular bricks is not new, for such articles were used by the Romans in large vaultings, where lightness of construction was required, and they are said to be in common use in Tunis at the present time. The size of the bricks is 12 inches long, and three courses rise 1 foot in height. 9 hollow bricks will do as much walling as 16 of the common sort, with only a slight increase in weight. In passing through the tile-machine, or in the process of drying, the bricks can be splayed at the ends for gables, or marked for closures, and broken off as required in use, or they may be perforated for the purpose of ventilation. If nicked with a sharp-pointed hammer, they will break off at any desired line; and the angles may be taken off with a trowel as in the common brick. The bricks for the quoins and jambs may be made solid or perforated, and with perpendicular holes, either circular, square, or octagonal: those in the quoins may be so arranged as to serve for ventilating shafts. The hollow bricks, from their mode of manufacture, are more compressed than

common bricks, require less drying, and are better burned with less fuel.

The following figures represent some of the forms of hollow bricks in common use. *a*, Fig. 1688, is an *external* brick $11\frac{3}{4}$ inches long, which with the *quoin* brick *e*, and the *jamb* brick, *b*, are sufficient for building 9-inch walls. *e* is $10\frac{1}{4}$ inches long, with one splayed corner for forming external angles, reveals, and jambs of doors and windows either square or

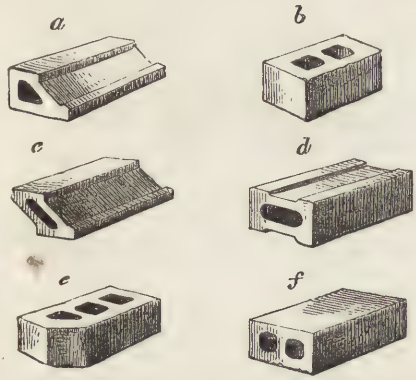


Fig. 1688.

splayed. The *internal jamb* and *chimney* brick, *b*, is $8\frac{3}{4}$ inches long; *c* is an internal brick adapted to any thickness of wall beyond 9 inches: *d* is for $5\frac{3}{4}$ inch partitions, or internal walls, and arch bricks, and is used for floor and roof arches of 7 to 10 feet span. *f* is used for the same purpose, with a webb to give extra strength and to adapt them for using on edges in partitions, $3\frac{3}{4}$ inch thick to rise in 6-inch courses.

Fig. 1689 represents a specimen of hollow brick work in 6-inch courses, with square rebated joints for extra strength. These bricks are adapted to the lining of flint or concrete walls. Fig. 1690 is a section illustrative of the construction adopted in H.R.H. Prince Albert's model houses. The span of the arches is increased over the living rooms to 10 feet 4 inches, with a proportionate addition to their rise. The external springers are of cast-iron connected by wrought-iron tie rods.

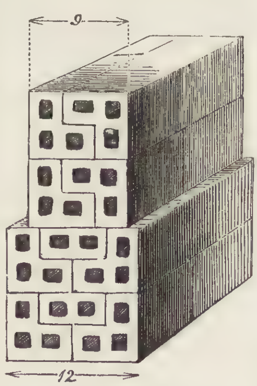


Fig. 1689.

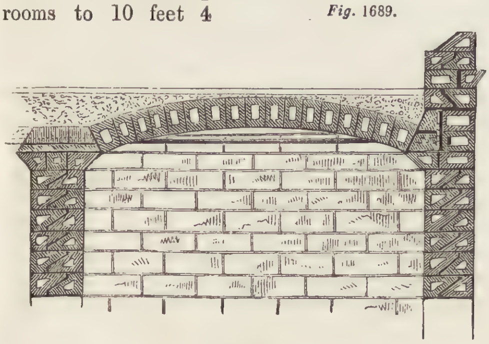


Fig. 1690.

It is stated that there is an advantage of 29 per cent. in favour of the patent bonded hollow bricks over ordinary bricks, in addition to a considerable diminution in the cost of carriage or transport, and of 25 per cent. on the mortar and the labour.

Among the articles in coarse pottery, which excited considerable attention in the Great Exhibition, were the gas retorts of fire-clay exhibited by Messrs. Joseph Cowen & Co., of Blaydon Burn, near Newcastle-on-Tyne. About 20 years ago each retort was made by Messrs. Cowen in 10 pieces; this number was reduced to 4, 3 and 2, until in 1844 the retort was made complete in one piece. The largest dimensions are 10 feet long by 3 feet internal width.

Mr. Lowe, the gas-engineer, remarks, with reference to these retorts and the fire-bricks manufactured by the same firm, "One especial feature in these bricks and retorts visible to the eye, and so essential to their withstanding high heats, is their freedom from iron, which acts the part of a flux, destroying the otherwise good properties of many fire-clays. This he arrives at by following the Chinese practice of submitting his clay for years exposed to all weathers, turning it frequently over, whilst young hands pick out the fossiliferous fragments, generally pyritous, which this disintegrating process lays open to observation. The clay contains a high per centage of silica. Add to these points great care in the manufactory, in which every appliance is to be seen, and we have nearly the secret of Mr. Cowen's fame. He has testimonials from all quarters, one from Rouen, stating 38 months as the durability of some of his retorts, being 4 times that of iron ones." Messrs. Cowen obtain their clay from no less than 9 different seams, so that they are able to mix their clays extensively to suit different purposes.

Fire-clay is found in England in the coal-measures, but it differs considerably in different districts. It is *refractory*, i.e. resists the action of fire, in proportion to its freedom from alkaline earths and iron, which render the clay fusible at high temperatures. The proportions of silica and alumina in these clays vary considerably, the silica from 50 to 70 per cent., and the miscellaneous ingredients from $1\frac{1}{2}$ to upwards of 7 per cent. The celebrated *Stourbridge clay* consists of silica 63·7, alumina 22·7, oxide of iron 2·0, and water 10·3 per cent. This clay lies about 15 feet beneath the lowest of 3 workable seams of coal, worked at Stourbridge, in the lower coal measures in the north-western extremity of the Dudley coal-field. The bed of clay is 4 feet thick. Some of the fire clays of other parts of England are now admitted to be nearly, if not quite equal to this.

Section IV.—Manufacture of Tobacco-pipes.

The manufacture of tobacco-pipes is a branch of the potter's art which derives importance from the immense demand for those small contrivances. Those who do not indulge in the use of tobacco may despise

a manufacture which ministers in no way to their wants, but rather excites their disgust. There might have been something of this self-satisfied feeling in the ancient Greek philosopher, who in passing through the fair at Athens, and seeing the shops filled with so large a variety of wares, exclaimed with a smile, "How many things are there that I do not want!" We too may smile at, and yet admire the large amount of science, energy, capital, and skill which are applied to meet a want as soon as it is generally expressed, or to gratify a whim or a caprice which may have become fashionable.

In the manufacture of tobacco-pipes there is much to admire. The pipe itself is an ingenious contrivance: the bowl is a kind of furnace in which tobacco is burnt; the chimney to this furnace is a long perforated stem, and the draught is excited by the lips of the smoker drawing air through the bowl: this supplies the ignited tobacco with fresh oxygen, and the products of combustion, consisting chiefly of nitrogen, carbonic acid, and oil of tobacco in a volatile form pass up the stem into the mouth of the smoker: the length of the stem cools the smoke, and deposits a considerable portion of the poisonous oil which is absorbed by the porous clay of the pipe, while the ashes, consisting of salts of potash, lime, &c., remain behind in the bowl. The comfort of the smoker is further consulted by the curve given to the stem, the effect of which in holding the pipe is always to maintain the bowl in its right position, while the small projection below the bowl serves as a guide in holding the pipe, or in passing the fingers down towards the heated part. There are many forms of clay pipe, but perhaps the best is that known as the old corporation pipe: it has a long stem, a large bowl, and a smooth surface, with a very slight yellow tint.

The clay employed in this manufacture occurs in the island of Purbeck in Dorsetshire, and in several parts of Europe, the lower portions of the deposits being most esteemed. The clay is carefully purified from foreign matters by some of the usual mechanical processes, and is formed into cubical masses of from 80 to 100 lb. each. From one such mass the moulder cuts off a number of lumps, each sufficient for one pipe, kneads them upon a table, and rolls them out nearly to the form and dimensions of the intended pipe, leaving a bulbous portion at the end for the bowl. When these rolls have become somewhat hardened by exposure to the air, they are bored by means of a wire mounted in a wooden handle: the man holds the roll between the three fingers and thumb of the left hand, and guides the wire very accurately by touch along the axis of the roll. The wire is slightly enlarged near the end, and this assists the operation. The roll thus impaled,

Fig. 1691.

Fig. 1691, is placed in the groove of one half of a copper mould, Fig. 1692, slightly brushed with oil in order that the stem may be smoothly delivered. The other half of the mould exactly fits by means of pins and hollows which correspond in the two halves.

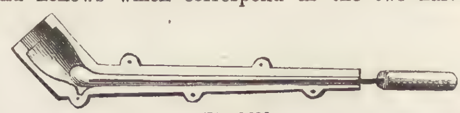


Fig. 1692.

The mould is next placed in an iron frame, Fig. 1693,

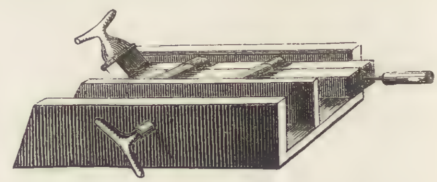


Fig. 1693

and its two parts are forced into close contact by means of nuts and screws. The clay of the stem is thus made to assume the form of the mould, together with any letters or ornaments which have been cut in the mould. The bowl is formed first roughly by the finger, and then by forcing into the mould the plug, Fig. 1694, which is held by its cross handle, while the rim determines the size of the cavity of the bowl. The bore of the stem is then continued until the wire touches the plug, but there is a small pellet of clay which precedes the wire, and this requires to be removed by a little hook attached to the handle of a kind of knife, with which the pipe, now removed from the mould, is finished by cutting away superfluous morsels of clay, &c. The top rim of the bowl is finished by a small copper mould, Fig. 1695. Ornaments which are not given by the pipe mould are now added by means of small rollers and stamps. Roughnesses are rubbed away by a small grooved iron tool, and polish is given by grooved agates. The pipes are next arranged in shallow trays, and left for some time to dry.

Fig. 1694.

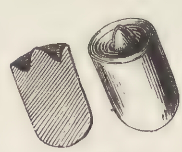


Fig. 1695.

Notwithstanding the number of processes which each pipe has to go through, a good moulder will produce 500 pipes a day.

In baking the pipes they are arranged in crucibles or seggars of pipe clay, strengthened by the insertion of broken pipe stems. The bottoms are framed of these stems radiating towards the centre, and the interstices are plastered with clay. The top of each is dome shaped, and a pillar of clay is placed in the centre through the whole height, for the purpose of strengthening the crucible and also of supporting the stems of the pipes. Each crucible is provided with six horizontal ledges running round the interior at equal distances: these support the bowls of the pipes, while the central pillar supports the stems. See Fig. 1696. As many as 50 gross of pipes can be arranged in one crucible. The crucibles are placed in a cylin-

drical kiln, Fig. 1696, with a circular fireplace at the bottom.

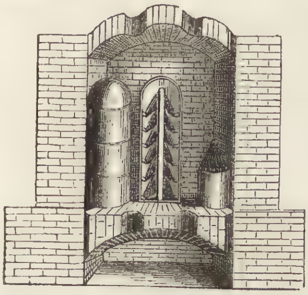


Fig. 1696.

The pipes should be of a fine white colour after the firing, and such clay only is in general selected as will produce that colour. It happens, however, in certain localities that clay, in other respects of excellent quality, becomes red in the firing, in consequence of the minute portion of oxide of iron contained in it becoming converted into the red peroxide under the influence of the oxidizing flame. The pipes come out of the kiln of a reddish hue. This defect has been remedied in an ingenious manner by the deoxidizing influence of carbon; for which purpose the kiln, when in full action, has its chimney and all other openings closed for about three quarters of an hour, the effect of which is to condense the smoke of the fuel upon the pipes in the form of soot. The holes are then unstopped and the fire urged for a quarter of an hour, the effect of which is to raise the pipes to a red heat and burn off the soot or carbon. This operation is repeated several times according to experience, but the last time the fire is urged for an hour. The effect of this treatment is to convert the red peroxide of iron into the pale green protoxide, which scarcely interferes with the white lustre of the pipes, except just within the bowl, which remains slightly red.[1]

By a somewhat similar process an opposite result is obtained, viz. the production of *black* pipes. The seggars containing the pipes are partly filled with oak sawdust, and placed in the upper part of the kiln where the heat is least. The carbon of the wood thus combines with the clay, and as it is not burnt off by exposure to air at a high temperature, the pipes come out of the kiln of a dull black colour: they are polished by being dusted with plumbago and then rubbed hard with a cloth.

Baked clay has so strong an affinity for water [see ALUMINA], that when a new pipe is put into the mouth it absorbs the moisture from the lips, and adheres to the skin with such force that if suddenly detached it might tear away the skin. We have heard of such a case, and of a dangerous wound being produced thereby. The usual remedy is to tip the end of the pipe with sealing-wax, but a better plan is to polish the pipes by dipping them into a mixture of fat clay and water, and then polishing off with flannel. For the better kinds of pipes a sort of varnish is made by boiling soap, wax, and gum in water, and applying it by means of a flannel with friction.

The bowls of tobacco pipes are also made of procelain, and highly ornamented. This is an example of pressed ware and of painting on porcelain, and calls for no special remark. *Meerschaum* pipes are noticed under MAGNESIUM.

SECTION V.—PREPARATION OF THE MATERIALS FOR POTTERY AND PORCELAIN.

Pure clay tempered with water forms a very plastic paste, capable of being easily worked. It is exceedingly impressible, and assumes any form which the fingers of the potter may impart to it. The sensitiveness of this material may be illustrated by stamping a seal upon a lump of clay, drying the lump and carefully paring off all traces of the impression; if the lump be now passed through the kiln the impression of the seal will be revived, thus showing that the molecules of the clay had received and retained the impression to a considerable depth below the surfaces.

But this sensitive plasticity of clay, which so admirably adapts it to the shaping of vessels and other articles, leads to some inconvenience in the firing; for the clay undergoes so large an amount of contraction by heat that thin wares become distorted, and are also liable to crack. And this distortion is not altogether due to contraction or to the unequal evaporation of the water: it is also occasioned by the tendency of the aluminous particles to return to their normal position, from which they were slightly disturbed in the process of *throwing* or turning on the potter's wheel. In this process the clay is spun upon a vertical lathe, and moulded by the pressure of the hand into continuous bands, spirally disposed, passing from right to left, from the base of the vessel to the summit. When such a vessel is raised to a high temperature the particles thus disturbed and the points thus compressed tend to return back to their normal position of equilibrium, as may be easily proved by marking upon the vessel, before it is fired, two points in a vertical line, when it will be found after the firing that these two points are no longer in the same vertical: the lower point will have moved more towards the right than the other, and this is so well known to the workmen, that on attaching handles to cups, jugs, &c., before the firing, they are accustomed to place them a little askew, and the distortion produced by the contraction in firing restores them to their vertical position.

This remarkable plasticity of clay is lowered down by the addition of a substance which does not possess that property in the slightest degree, viz. silica. This substance is prepared from flints, quartzose sands, felspar, &c., but these are not the only nonplastic materials employed; for chalk, sulphate of baryta and calcined bones are used with good effect.

In the manufacture of earthenware two principal ingredients are employed, *clay* and *flint*. The nature

(1) This method was communicated in 1730 by a manufacturer of St. Omer to Duhamel du Monceau, whose treatise on the manufacture of pipes written for the celebrated treatises on "Arts et Métiers," of the Academy of Sciences has served as the text for most writers on this subject up to the present day. It is some encouragement to the Editor to pursue his laborious task, when he finds such men as Réaumur and Duhamel devoting their time and splendid talents to the preparation of elaborate treatises on the Useful Arts

and proportions of these rest with the manufacturer, and upon the soundness of his judgment in these respects, more than in any peculiar art of construction, depends the excellence of his ware. The clays commonly used in the Staffordshire potteries are brought from Devonshire and Dorsetshire, *brown* and *blue* clays from the latter, *black* and *cracking* clays from the former. The black clay owes its colour to the presence of bitumen or coaly matter, but this disappears in passing through the potter's oven, so that the wares formed of it are nearly white. Cracking clay is valuable for its pure white colour, but is liable to crack during the first burning, and must therefore be mixed with other clays which have not this tendency. Brown clay is also liable to an imperfection called *crazing* or cracking of the glaze. Blue clay is the best for ordinary purposes; it will bear a larger proportion of flint than the others, and therefore produces a whiter ware. For the finer kinds of earthenware, a fifth variety, being the *china clay* of Cornwall, is largely employed. This consists of felspar, one of the ingredients of granite, in a partially decomposed state. It is collected in the following manner:—The stone is first broken up with a pick-axe, and thrown into a stream of running water. This washes off the argillaceous parts, and keeps them suspended while the quartz and the mica (the other two ingredients of granite) sink at once to the bottom. At the end of these rivulets the water is dammed up, forming what are called *catchpools*, and here the pure clay subsides in a solid mass, which is afterwards dug out in blocks, (the water being drawn off,) and laid on connected series of strong shelves, called *linnees*, to dry. It is then crushed, packed in casks, and sent to the potteries as *china clay*. In this state it is a white impalpable powder, consisting of 60 parts alumina, and 20 silica. A certain proportion of undecomposed felspar is often added, as it serves to bind the ingredients more closely together. Neither clay, flint, nor lime can be melted separately in the greatest heat of a porcelain furnace, yet when mixed together in proper proportions one mineral acts as a flux to the others, and the mass can be fused without difficulty.

Flints for the manufacture are obtained from the chalk districts, chiefly of Gravesend and Newhaven. They are white externally, but dark and clear within. When the fracture exhibits yellow spots, the flint must be rejected as containing iron which would stain the ware. Steatite or soapstone occasionally forms one of the ingredients in the manufacture of porcelain.

There is a mineral called *pegmatite*, in which all the materials for hard porcelain exist ready mixed. Pegmatite consists of felspar, kaolin, and a small quantity of prismatic quartz, the last being valuable for the whiteness and transparency which it imparts. Therefore a good pegmatite, well decomposed, is all that the manufacturer requires. Soft porcelain, as it is manufactured at the present day, consists of two ingredients from the mineral kingdom, and one from the animal kingdom, viz. kaolin, Cornish stone, and bones. The last melt into "a sort of semi-transparent enamel," which gives transparency to the porcelain according to the quantity used.

The preparation of these materials involves many processes and much labour and care. The first process is the mixing of the clay, and is called *blunging*. The proper proportions of blue and white clay are placed overnight in a trough about two and a half feet deep, with the needful quantity of pure water. In the morning these are well incorporated with the water by means of a long blade of ashwood with a cross handle at its upper extremity, called a *blunger* or *plunger*. This is worked violently in the trough until a smooth pulp is obtained, a pint of which is, by the addition of water, made to weigh 24 ounces, but when china-clay is used, a pint is made to weigh 26 ounces. To facilitate the blunging process, the clay is sometimes pugged in a cast-iron cylinder, 4 feet deep and 20 inches in diameter, through the centre of which runs an upright shaft furnished with a spiral line of knives inclining downwards. A corresponding series of knives is fixed to the inside of the cylinder, so that as the shaft revolves the knives cut up the clay, and by their inclination force it downwards. In its divided state it then passes through an opening in the bottom of the cylinder, whence it is removed to a vat, mixed with water, and blunged by means of a perpendicular shaft furnished with cross-arms. During the revolution of the shaft, the finer particles of the clay mix with the water, and the stony substances which may be present sink to the bottom.

Fig. 1697. BLUNGING.

The preparation of the flints involves several processes. They are first burnt in a kiln for about 30 hours, and either thrown into cold water while red-hot (which greatly increases their brittleness), or allowed to cool before being taken out. They are next placed on a strong iron grating, and acted upon by powerful stampers, or wooden beams shod with iron, Fig. 1698. These reduce the flints into fragments sufficiently small to pass through the grating. These fragments are conveyed to the *flint-pan*, Fig. 1699, consisting of a strong circular vat, 10 or 12 feet in diameter, the bottom of which is formed of quartz or felspar in small blocks, imbedded in mortar of a similar composition to the material which is to be

ground. In the centre of the vat is an upright shaft, surrounded by a barrel or hoop, 14 inches high,

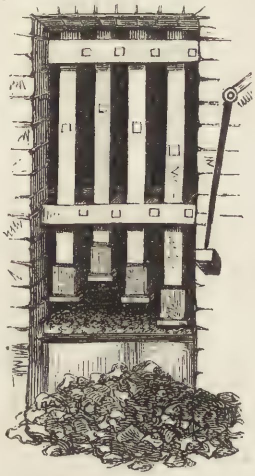


Fig. 1698. FLINT-MILL.

to prevent the materials from being soiled by the moving power while being ground. From the central shaft project 4 strong frames, which move the runners, consisting of very hard siliceous stone called

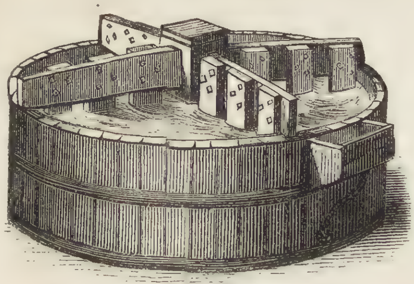


Fig. 1699. FLINT-PAN.

chert, found abundantly near Bakewell, in Derbyshire. Water, to the depth of 8 inches, is put into the vat, the broken flints or felspar are added, and the central shaft being put in motion, the broken pieces are forcibly rubbed against the runners, as well as against each other and the paving of the vat. In the course of some hours the flints are reduced to powder, and the mixture has the consistence of thick cream. Smaller vats of the same construction are used for grinding the felspar, broken porcelain, &c., used in the composition of earthenware. This flint-pan was the invention of the celebrated Brindley, and has been the means of preserving the work-people from the fatal effects of the dry method of grinding flints which was previously employed, and which was nearly as injurious as the grinding of needles and edge-tools. The stones employed in the construction of flint-pans require to be very carefully selected, or great loss may accrue to the manufacturer. Should the stones contain much carbonate of lime, this would mix with the flint in grinding, and eventually with the ware itself, which would thus be rendered fusible in the kiln, or blister from the escape of carbonic acid. When the flints are sufficiently ground in the flint-pan the creamy mixture is passed into another vat having an upright shaft and arms, by the revolution of which, and the addition of a further quantity of water, the finer particles of flint are kept suspended, while the larger and heavier particles sink to the bottom. The water containing the finer particles is drawn off into a reservoir, where the powder subsides. The flint powder is considered fit to mix with the clay when a wine-pint of it weighs 32 ounces, while an equal bulk of the diluted clay should weigh 24 ounces. The densities of these two principal ingredients being taken, the manufacturer is able to mix them in proportions varying according to the kind of ware to be made, and according to his own particular plans, for each manufacturer usually has his own independent mode of operation.

The prepared clay and flint are united by agitation, and the fluid mixture is then passed through sieves of hard spun silk, manufactured expressly for the purpose, and arranged on different levels, as shown in Fig. 1700, so that the mixture shall pass from coarser to finer sieves, and be at last reduced to the utmost

Fig. 1700. MIXING THE INGREDIENTS.

uniformity and smoothness, a constant jigging motion of the sieves being kept up by machinery. The mixture thus strained and purified is called *slip*, and has now to be brought into a doughy consistence for the use of the potter. For this purpose it is conveyed to the *slip-house*, and boiled in the *slip-kiln.* The English slip-house is a long low detached building, with the tiles placed half-way apart to allow of the more ready escape of steam. The slip-kiln, a portion of which is shown in Fig. 1697, consists of long brick troughs with flues under them for heating the mixture to the boiling point. During the early part of the evaporation it is necessary to keep the mixture constantly stirred to prevent the heavier flint from subsiding; if this were not done, one part of the clay would contain too little, and another part too much flint. There is also a tendency in the flint and clay, when water is present, to form a sort of mortar, which speedily hardens, but this is prevented by diligent stirring. The slip remains in the kiln about 24 hours, and towards the close of this time bubbles of steam cease to be formed on the surface, and the mass, when cut into, appears to be of a uniform texture, and sufficiently hard. The abundance ot

fuel in England has led to the wasteful and unscientific application of it in many of our manufactories, and the slip-kiln is one out of numerous examples. In countries where fuel is scarce, the slip is deprived of its superfluous water by other means. In the potteries of Röstrand near Stockholm the slip is placed in large square boxes, and exposed to the air with a southern aspect, by which means a large quantity of water is got rid of by the natural process of evaporation. The boxes are furnished with covers, which are lowered in rainy weather. When a certain quantity of water has been got rid of in this way, the paste is put into the hollow cavities of thick plaster moulds, which absorb sufficient water to bring the paste to the proper consistency for working. It is necessary to keep the slip in a state of agitation in the moulds, or the resulting paste will be denser where it comes in contact with the plaster than in the other parts. This plan can only be practised on a small scale; but we are now about to notice two methods, both of which deserve the serious attention of manufacturers. The first consists in enclosing the slip in sacks of strong and closely woven texture, and then subjecting it to a considerable pressure, which may be economically supplied by means of a long lever loaded at the end of the long arm, and a number of sacks being placed between two boards near the end of the shorter arm, the pressure is thus maintained as long as it is required. A press of this kind will prepare for use about 1,300 lb. of porcelain paste in 3 hours. A screw press worked and attended by 2 men, will prepare in a day of 12 hours from 1,350 to 1,575 lbs. of porcelain paste.

It will be seen that this method is a species of filtration accelerated by mechanical pressure. A more refined and successful plan is to filter with the aid of atmospheric pressure, for which purpose the filter is placed above the vessels A A, Fig. 1701, from which the air can be removed by connecting them at bottom with a tube about 36 feet long, terminating at its lower extremity in a reservoir of water C. If one of these vessels be full of water, and be made to communicate with the reservoir by means of the long pipe, a vertical column of water from 40 to 50 feet in height will thus be formed; but as the atmospheric pressure is only equivalent to a column of about 34 feet high, [see AIR,] it is evident that the upper part of the column will sink down to that height, or in other words, the vessel A will discharge its contents into the reservoir C by means of the pipe, and thus form a vacuum above. The slip is contained in the filtering vessels, F F, above, in the centre of each of which is an opening communicating by pipes with the vessels A A. This opening is covered with an iron grating *g*, and a bed of pebbles, *p*, is made to cover the rest of the conical part of the filter. The grating and the pebbles are covered with a cloth of thick spongy felt, pervious to water but not to the solid particles of the slip, firmly secured at the edge of the filter, and above this is another cloth of hemp for receiving the slip. On opening the stop-cocks *c c*, so as to connect one of the filtering vessels with one of the vacuum vessels, the atmospheric pressure not being counterbalanced below,

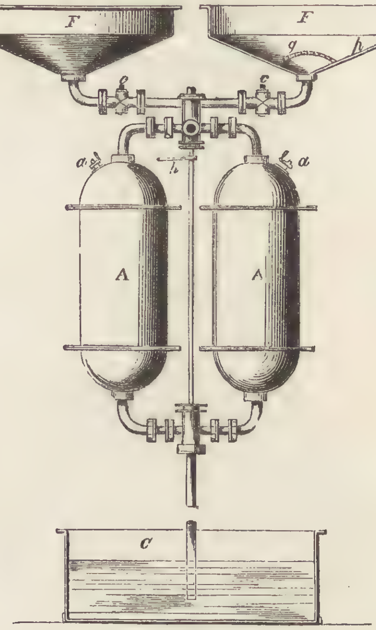


Fig. 1701.

exerts its whole action on the surface of the slip, and forces the water through the filtering cloth into the vacuum. In the course of 40 to 45 minutes a layer of slip about 6 inches deep, containing rather more than 50 per cent. of water, is reduced in depth to about $2\frac{1}{4}$ inches, and is converted into a paste of remarkable plasticity and containing only one-fifth of water. This apparatus is better adapted to the preparation of porcelain than of pottery paste. For the

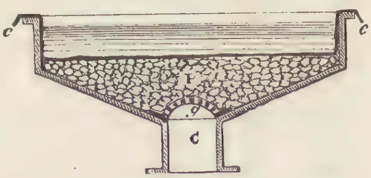


Fig. 1702.

latter the form of apparatus shown in Fig. 1702 may be used. In this the vacuum is produced by injecting steam into cylinders C, placed below the filtering bed. The vessel containing the filter is of cast-iron; the filtering cloth is shown at *c*, resting on its bed of pebbles P: *g* is the grating as before.

In the English process, when the slip has been reduced to the proper texture in the kiln, it is removed to another part of the slip-house, where the process of *wedging* goes on. This consists in cutting up the mass from the slip-kiln into wedges by means of a spade, and dashing them against each other to get rid of vesicles and air-bubbles, which would otherwise form blisters in the ware. This wedging should be carried on at intervals during several months, to secure a fine grain and freedom from flaws. In China, we are told, a store of clay is prepared 14 or 20 years in advance, and sometimes a potter will prepare suffi-

cient porcelain clay for the use of his son during his lifetime. Modern customs scarcely allow of such arrangements, but every manufacturer knows the superior value of clay that has been kept a considerable time, and the mischief which often ensues from the use of clay warm from the slip-kiln, or which has been lying only for a few days. During this *ageing* of the paste a true fermentation goes on. Carbonic acid gas and sulphuretted hydrogen are disengaged, and the mass in the course of time improves both in texture and in colour. It is probable that certain carbonaceous and organic matters in the clay or in the water with which it was blunged, are the cause of this fermentation. At any rate, they are thus got rid of, whence the improvement in the colour of the clay; and the gas in struggling to escape, produces a kind of natural wedging and slapping, thus excluding particles of air, and reducing the clay to a homogeneous mass. The process of *slapping* somewhat resembles that of wedging. The workman takes a mass of the paste, weighing 60 or 70 lb., and dashes it down upon a bench before him. He then divides it repeatedly, by drawing through it a wire furnished with a handle at each extremity; and on each division he takes up one portion of the clay and dashes it down with great force on the other portion. Care is taken to preserve the *grain* of the paste; that is, the layers are slapped parallel to each other, and not at right angles or obliquely, otherwise the ware would be liable to fall to pieces in the baking.

Section VI.—Throwing, Turning, Pressing, and Casting.

The clay, being thus brought to the requisite state, is next shaped into articles in earthenware by one of three processes, named *throwing*, *pressing*, and *casting*. Of these, throwing is the most ancient, as well as the most interesting, on account of the skill required in the workman. It is performed at the potter's wheel or lathe, which consists of an upright shaft about the height of a common table, on the top of which is fixed a disk of wood of sufficient diameter to support the largest vessel that is made. The lower end of the shaft is pointed, and runs in a conical step, and the upper part in a socket, a little below the circular board. The shaft has a pulley fixed upon it, with grooves for 3 degrees of speed, over which an endless band passes from the fly-wheel, by the revolution of which any degree of speed may be given to the shaft, and its top-board. When this wheel is small, it is placed alongside, and driven by a treadle and crank; when large, it is turned by an assistant, as shown in Fig. 1703.

The mass of dough, as received from the slapper, is cut up into portions with a brass wire, each portion being weighed, slapped with the hand, and rolled up in a ball. A female assistant, called a *baller*, often performs this. The thrower, seated with one foot on each side of the wheel-head, with his elbows supported on his knees when his hands require to be kept steady, takes one of these balls, dashes it down upon the centre of the revolving-board, and with both hands kept wet by occasional dipping in water, he squeezes up the clay into a high conical lump, and again forces it down into a mass to get rid of any remaining air-bubbles. With one hand or finger and thumb in the mass, he then gives the first rude form to the vessel, and with a piece of horn, shell, or porcelain, called a *rib*, which has the profile of the shape of the vessel, he smooths the inner surface, gives it

Fig. 1703. THROWING.

the proper shape, and removes the inequalities left by the fingers. In the meantime the assistant keeps the wheel moving at varying degrees of velocity according to the requirements of the thrower. In order to make a number of vessels of exactly the same size, he does not entirely rely upon his eye, but employs a simple kind of gauge, consisting of a peg, or stick, placed opposite to him, at a certain distance from the centre of the vessel, whereby he is able to judge of the required height and diameter of the vessel which is being formed. The thrower's work is simply to produce circular vessels, such as tea-cups, basins, &c., without handles or ornaments, these being added afterwards.

We may further illustrate the thrower's art, by Fig. 1705, which we sketched at Doulton & Co.'s Lambeth potteries. The clay used in this coarse stone-ware is obtained from Poole, Teignmouth, &c. It is placed in large lumps round the kilns to dry. It is next mixed in certain proportions, crushed under edge wheels, and mixed much in the same manner as mortar is. It is well assimilated by being passed through a pug-mill in which the arms and spikes are arranged on the central axis, somewhat after the manner shown in Fig. 1704. The clay is then weighed up into balls of the size of the intended article, which in the case now to be noticed was a 3-gallon bottle. The rough ball No. 1, being dashed

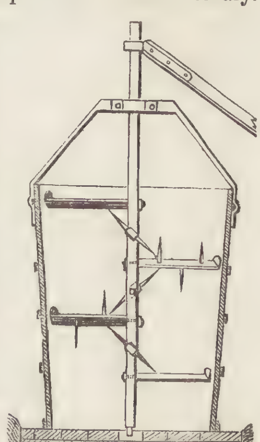


Fig. 1704.

down upon the board, the attendant sets it revolving by turning the winch as shown in Fig. 1706. The man then with hands made very wet with water, raises up the ball into the conical mass, No. 2, for the purpose of squeezing out the air, and rendering the mass as homogeneous as possible, effects which are produced in the paste for the finer kind of pottery ware by ageing, wedging, and slapping, as already noticed. The man next presses down the conical mass so as to form the dumpy figure No. 3, in which he carefully forms the bottom of the vessel by his fingers and also by means of a rib. The next operation, called *knuckling-*

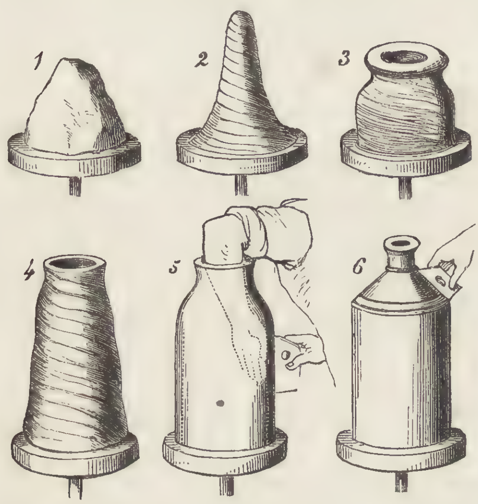


Fig. 1705. SUCCESSIVE STEPS IN THE THROWING OF A STONE-WARE BOTTLE.

up, is performed by placing one hand in the vessel No. 3 and the other on the outside, and pressing the clay between the knuckles of the two hands, at the same time raising the arms, the thick sides of No. 3 are thinned out into No. 4, the board or wheel of course being kept revolving all the time at various rates of speed as experience suggests. The next process is to make the sides truly cylindrical, which is done by the hand inside and a flat rib outside opposed to each other. A flat surface somewhat corresponding to the rib is formed by the hand inside by stretching out the index finger straight against the thumb as shown in the figure. The wide parts of No. 5 being carefully finished, the neck is gradually contracted and the top finished as in No. 6. The bottle is then cut off by passing a wire between it and the board, but before removing it from the board a list stopple is put into the mouth for the purpose of confining the air. If it were not for this simple but not very obvious precaution the large heavy mass of soft hollow clay would collapse in being removed, but by stopping the mouth the enclosed air acts as a sort of cushion or elastic support to the mass. When the bottle has become sufficiently consolidated by drying it undergoes the operation of *turning* (see Fig. 1706,) as will presently be noticed, the handle is glued on by means of slip, and it is ready for firing.

In large potteries, where a number of potters' wheels or lathes are in use, they are turned by means of the steam-engine of the establishment. In order to vary the speed the band for each wheel is passed over two cones, and the band is under the control of

Fig. 1706.

the thrower's foot by means of a forked lever, so that he can shift it at pleasure to a wide or to a narrow part of the cone.

As soon as one vessel is formed, and cut off at the base with a fine brass wire, the baller supplies another ball of clay, and the new-made vessel, (now said to be in its *green state*,) which he lifts off the wheel, is placed on a board, and when a sufficient number are collected, he carries the whole into the open air, or into a warm room, where they part with their moisture sufficiently to allow of the next process which is *turning*.

The turning of earthenware in the Staffordshire potteries, does not differ from that of wood, ivory, or metal, and it is a curious sight to watch a rude clay cup or bowl spinning round in the turner's lathe, with long and broad shavings flying off from it, under the operation of the cutting tools. That the turner may stand quite steady at his work, motion is given to the lathe by an assistant *treader*. This is usually a female; and while employing her right foot at the treadle, she also attends to the green vessels on the board, moistening their upper edges, and clearing away whatever interferes with the turning. A clay ring, scarcely moist, is kept on the chuck, the vessel is put on it with the upper edge (already moistened) turned downwards, and pressed into the clay ring. The surplus clay, left by the thrower, is then rapidly removed by the tool, and the vessel brought to the required thickness. When this has been completed, and any desired fanciful indentations and cuttings have been made, then a retrograde motion is given to the spindle, during which the upper surface of the vessel is smoothed and solidified by the pressure of a broad tool, and the vessel is then cut loose, and delivered to the handler, or it is dried for the biscuit oven. Clay for handles, spouts, &c. is first formed into pipes at a small press, which forces the clay through a metal tube of the required size and form. The clay pipes, thus formed, are cut up into lengths, and shaped with the hand. They are attached to the articles by means of slip, which unites them quickly and perfectly. Superfluous clay is scraped off with a knife, and the vessel cleaned with a damp

sponge, to give it a uniform appearance. Plaster-of-Paris, or steel moulds, are used where figures and foliage are required, and are attached as before. In some cases flowers and leaves are formed by hand, with considerable dexterity and attention to botanical character. The Editor has witnessed the skill exhibited in this respect by the artists employed in the celebrated porcelain works at Meissen, near Dresden, where a botanist of talent is employed to superintend the operations.

When articles have to be executed on a large scale, the method is the same in principle as that just alluded to of forming ornaments in moulds, and is called *pressing*. Plaster moulds of every variety of size and pattern are employed in great numbers, for all plates and dishes are thus manufactured, and a complete set of patterns is required for every new pattern, and for every size of the same pattern. Moulds for plates and other shallow articles consist of only one piece, and are formed by taking the impression of the inside of the article, or the upper surface of the model in plaster. Plates, dishes, saucers, cups, and hand basins are now made by the process of *flat-ware pressing*, an operation which is conducted as follows:—a plate being taken as an example. The plate-maker stands at a bench before a *whirling table* similar to the thrower's, but moved by a horizontal pulley or jigger turned by a boy. On his left hand is a *batting block* of wet plaster and a mass of well beaten clay. Near him is the stove-room in which moulds are ranged on shelves to dry. The plate-maker first cuts his clay into lengths with a wire, and tears off a piece which he batts out thin upon his block by a stroke or two of his *batter*, which is a plaster mallet, and he polishes the surface of the batted clay by pressing the side of a smooth knife against it. The boy then places a mould on the whirler, and stations himself at the handle of the jigger: the man places the clay on the mould, which is then set whirling, and he presses it down close with his hand. A profile or earthenware tool, which gives the form to the bottom of the plate, is next pressed upon it as it revolves. Where great precision is required, the profile is mounted in a carrier C, Fig. 1707, which can be adjusted by screws upon

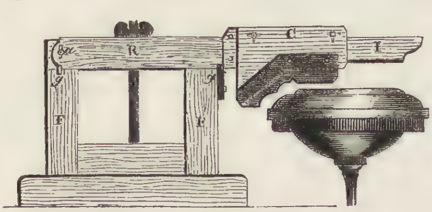


Fig. 1707.

the arm I of the frame F F, and fixed to the proper height by the screw R. The arm I descends in a groove *g*, to the exact depth required for the thickness of the plate. When the proper shape is given the motion is stopped, and the boy catching up the mould with the plate upon it runs with it to the hot room, places it on a shelf to dry, and returns with an empty mould which has been drying. In the mean time the man has batted out another piece of clay for another plate. In about two hours, the plates become sufficiently dry to be removed from the moulds, but the moulds themselves having absorbed much moisture from the plates, are left to dry before they can be again used. One workman, with the assistance of two boys, can make from 60 to 70 dozen of ordinary plates in a day of 10 hours, using the same moulds about five or six times in the period.

The whirling table having a circular motion, is of course only adapted to articles with a circular outline. At the Royal porcelain works at Meissen we saw a whirling table with an elliptical motion, adapted to dishes and other articles. For articles of less regular figure, the whirling table is not moved by a wheel and strap, but is simply supported at the end of the vertical rod, and left free to turn on receiving a gentle impulse from the moulder. Where the surface of a large article has to be covered, the clay is rolled out upon a moistened sheepskin, the rolling-pin being supported by two guide rules. The clay is lifted by means of the skin, placed upon the mould, pressed, smoothed, and adjusted, and finished with a wet sponge, and wet leather. The edges are then trimmed, and the maker's name or other mark is stamped upon the back.

The above simple form of pressing is not applicable to deeper vessels, which are made by what is called *hollow-ware pressing* or *squeezing*. The mould in this case is made in several parts, accurately fitting together, as shown in Fig. 1708, which represents a mould for a

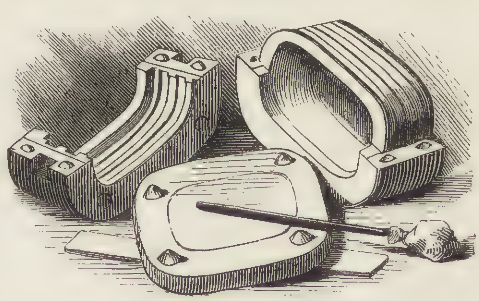


Fig. 1708.

foot-pan. The base of the mould has 4 projections, which fit into cavities of the two halves for the upright portion. One of these uprights is shown with the pan in it in the act of being detached. In moulding such an article, the clay is well kneaded, batted out, and spread over the bottom, which is placed on a whirler or flat board mounted on a vertical axis, so as to turn round easily: the two halves are each lined with clay, which is well worked into the grooves and made to project a little at the edges. Each half is then placed upon the base piece, and secured by passing a string round the outside of the mould. The joints are then well worked with the wet finger, and fresh clay added, and slip applied so as to make the seams adhere perfectly. The mould is then put aside, and another filled in like manner. Handles for large vessels are prepared in plaster dies or moulds. For *lugs*, or solid handles, the clay is well rammed into

the hollow mould, shown to the left of Fig. 1709, then inverted and dashed down upon the mass of clay shown to the right of Fig. 1709. The mould is then

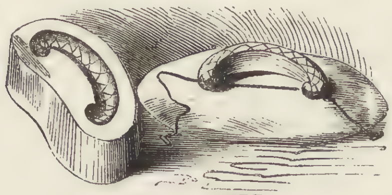


Fig. 1709.

Fig. 1710.

taken up, leaving the moulded lug on the mass, from which it is removed by passing a wire under it. For open handles the moulds are in two parts; these are filled separately with clay, and then put together and struck, as shown in Fig. 1710, which causes the two sections of the clay to adhere. On opening the mould, the handle is taken out entire, and fettled smooth.[1] The method of forming pressed wares in Staffordshire is as follows. The presser first kneads and bats out a number of pieces of clay. One of the sections of the mould is placed on the whirler, and a bat is forced into it with a moist sponge, and worked well into every part. All the sections being thus lined with clay, the edges are trimmed, moistened with slip, and the parts of the mould are carefully brought together, and secured by a strap passed round them. The presser then passes his finger up every joint, so as to make a groove, into which a thin roll of clay is inserted, worked in, and smoothed with moist leather or a cow's lip. All marks are removed with a sponge, and the inside is washed with pure water. The mould and its contents are set aside for awhile, then again placed on the whirler, and polished with a flexible plate of horn. It is then placed in a warm room, and when sufficiently dry, the article is removed from the mould and *fettled*, or trimmed with proper tools, so as to remove all appearance of seams. The outside is cleaned and polished with moist sponge, the handles, &c., are added, and a little more polishing with the horn completes it. It is then set aside to dry previous to baking. For original or elaborate designs, the services of experienced artists are required to form, in the first instance, models in clay. At Meissen, the Editor saw models of a complicated kind for four vases, emblematical of the ancient elements—fire, air, earth, and water—the moulds for which consisted of 150 separate pieces. When the articles are of a simple character, they are formed by a union of throwing and moulding.

Delicate articles for ornamental purposes are formed by *casting*. The clay and flint being mixed with pure water to a creamy state, are poured into moulds, the plaster of which quickly absorbs water from the portion which comes in contact with it, and hardens it sufficiently to allow of the central fluid portion being poured off. A coating of clay is thus left attached to the mould, and when this is partially dry, a second layer of clay is poured in, which serves to give strength and consistence to the first. The superfluous portions of this second layer being also poured off, the mould with its contents is placed in a stove, until sufficiently dry to be separated. The cast is then taken out, and carefully examined and retouched by the modeller. In this way porcelain statuettes are manufactured. The lace which sometimes adorns them, and which appears as if originally formed of porcelain, is actual manufactured lace, dipped into slip, and thus fully imbibing the porcelain material. The heat of the furnace destroys the thread while it hardens the porcelain material which takes its place: hence the curious and beautiful effect.

The processes described in this section belong for the most part equally well to pottery or porcelain paste. We may, however, notice a few special articles made in one or other of these materials.

A very interesting variety in the porcelain manufacture has been invented by our English makers, and called *Parian*, *Carrara*, or *statuary* porcelain. It was introduced six or seven years ago by some enterprising Staffordshire firms, and it certainly presents a great similarity of effect with the beautiful marbles after which it is named. This effect is attained chiefly by the employment of a soft felspar in the porcelain instead of Cornish stone. The agreeable yellowish-white tint which characterises this material is not due to any colouring matter mixed up in the compound, but to the small quantity of oxide of iron contained in the clays and the felspar. During the firing, as the atmosphere of the inside is oxidizing, this small quantity of iron forms with the silica a silicate of peroxide of iron, which gives the colour. These figures, instead of being pressed in moulds in the regular way, are cast with the compound prepared in a liquid state: this causes a diminution of their bulk in the firing process, amounting to no less than one-fourth. Consequently much dexterity and a knowledge of the human figure are required in this manufacture, for the subjects are cast in a number of separate pieces, and their subsequent joining and repairing call for much skill in the artist. "If we compare our Parian," says M. Arnoux, "with the biscuit made on the continent, we shall perceive the enormous difference in their relative appearance: while the continental biscuit acquires in firing a greater sharpness, it is the reverse in the Parian; whilst the former, with its hard, cold appearance, will reject the light, this light penetrating into the latter to a certain depth, gives it

(1) Several of our figures are from sketches made at the potteries of Messrs. Doulton & Watt, of Lambeth.

a softness which has never been realized before."[1] In addition to the beautiful figures in Parian which appeared in the Great Exhibition, there was a novel and successful adaptation of this substance to the purpose of a chimney-piece, exhibited by Messrs. Minton.

To the same manufacturer we owe the revival of a curious, but long-neglected substance, called *majolica*, or *Majorca* ware, from the seat of its early manufacture. In the 16th century this material was manufactured in great perfection in Italy under royal patronage, and beautiful services of it were made, and decorated with paintings after the best masters. It was then valued as much as we esteem the finest porcelain, although, in fact, it was nothing more than a calcareous clay gently fired, and covered with an opaque enamel of sand, lead, and tin. But this enamel afforded an excellent ground for painting, and the designs of Raffaelle gave a name and distinction to this ware, while a variety of grotesque and quaint devices were also used to adorn it. Mr. Marryat, in his "Collections towards a History of Pottery and Porcelain," gives an account of this ware, derived from Passeri's scarce work. The purposes to which it was applied, while in vogue, were many and various. Cisterns, vases, ewers, *amatorii* (vessels adorned with the portrait of a favourite lady), nuptial vases, small plates for ices and sweetmeats, vases for holding different kinds of wine poured out from one spout, small flasks in the shape of apples and lemons, cups covered with tendrils, statues of saints, birds coloured after nature, painted tiles for walls and floors, are among the articles mentioned as being many of them of admirable workmanship. This majolica, it is thought, revived at the present day, may be useful for friezes and other architectural ornaments, and also for slabs to be painted on, forming a cheap material in which the colour would sink, and be equal in brightness to that attained on the enamelled surface given to copper. The flower-pots and vases of majolica in the Exhibition gained much praise.

Another manufacture, which has been greatly fostered by the revived taste for decoration of the present day, is that of *mosaic*, *plain*, and *encaustic tiles*. The processes of the manufacture, as we examined them a few years ago, at the works of the Messrs. Minton, of Stoke-upon-Trent, are as follows:—Encaustic tiles consist of a body of red clay, faced with a finer clay, which bears the ornamental pattern, and strengthened at the base with a thin layer of a clay different from the body, which prevents warping. The red clay or marl, forming the body of the tile, is obtained from Cobshurst, about four miles from Stoke-upon-Trent. It is dug out and left to undergo *weathering* or *wintering*, namely, exposure to the air for upwards of half a year. A portion of this clay, when brought into the factory, is thrown into a tank with water, and worked about with a blunger. When partially divided it is laded into another tank, and regularly blunged; this operation is again repeated, and the clay is passed through sieves of varying fineness, and, with a certain admixture of other compositions, is afterwards either dried into hard lumps and ground, or evaporated at the slip-kiln, according to the method which is to be employed in its subsequent treatment.

In the manufacture of what are called *dry tiles*, according to the method patented by Mr. Prosser, the powder, as it comes from the mill, is placed on slabs of plaster-of-Paris, slightly damped. It is then sifted through fine sieves, and subjected to intense pressure, by which the particles of powder unite into firm solid slabs or tiles. This is effected in the following manner. At the lower extremity of the screw of the press is fixed a steel plate, of the size and pattern of the intended tile: this fits into the upper part of a steel box of the same dimensions, the bottom surface of the box being ribbed, that the tile, receiving a ribbed impression on its under surface, may adhere more strongly to the mortar or cement by which it is imbedded in the wall or pavement. A portion of the powder being swept into the metal box, the steel plate is forced down upon it, with a pressure which may amount to 400 tons. A thickness of 3 inches of powder is thus compressed into a tile 1 inch thick, with sharp edges, and a beautiful polished surface. Tiles, scale-plates, table-tops, furniture panels, and other articles of considerable size, are thus produced, also, with smaller presses, tesseræ for mosaic work, and ornamental buttons for shirt studs. These articles are taken from the press to a hot room, for a week or two, where they are ornamented, glazed, and fired. It appears that new improvements have been made in this manufacture since the Exhibition closed. Steam power is now employed, so that the pressure on each tile is mathematically the same, and those slight variations, inevitable in work regulated by hand, are now avoided. "Each machine can make 5,000 tiles in 24 hours, and as soon as applied to the tesseræ the number will not be less than 115,000 in the same time. Only one man is required, viz. to take the tiles as they come out finished from these machines."

Encaustic tiles are made from the clay after it has been evaporated in the slip-kiln. It is wedged and slapped in the usual manner, and then slapped into a block, of the form of a cube, or parallelopiped, and placed before the tile-maker, who cuts off a square slab by passing a wire through it: upon this, the facing of finer clay, coloured to the desired tint, is batted out and slapped down; it is then turned over, and a facing is applied to the bottom of the tile to prevent warping. The tile, thus formed, is next covered with a piece of felt, and put into a box press: a plaster-of-Paris slab, containing the pattern in relief, is then brought down upon the face of the tile, and impresses in the soft tinted clay the design which is afterwards to be filled up with clay of another colour. The maker's name is then stamped on the back, and a few holes to make the mortar adhere. The pattern now remains deeply indented in the face of the tile, as shown in Fig. 1711, and over this is

(1) Lecture on the Ceramic Manufactures, &c. of the Great Exhibition, read June 2, 1852, by L. Arnoux, Esq., before the Society of Arts

poured a quantity of slip or clay in a semi-fluid state, and generally of some rich or deep colour. This completely covers the surface, and hides the pattern, which is to be revealed by an after process. In 24 hours the slip becomes tolerably hard: the tile is then placed on a small whirler, and the pattern and the ground are brought out by scraping away the superfluous clay, Fig. 1712, and leaving it only in the depression caused by the pattern mould. The whole is finished with a knife, and defects corrected: the edges are squared, and their sharpness rounded off with sand-paper. The tiles are kept for a week in a warm room called the *green-house*, whence they are subsequently conveyed to a *hot-house*, where strong heat completes the drying. They are then arranged in seggars, and fired as in baking pottery and porcelain, only about double the time is required. The oven is left to cool for six days, and the tiles are then drawn in their finished state. These tiles contract in firing to the extent of $\frac{1}{8}$th or $\frac{1}{16}$th in every inch. The dry tiles contract about from $\frac{1}{10}$th to $\frac{1}{20}$th. The above process is nearly the same as that employed in the middle ages, in making pavements for churches both in France and England, and also for the beautiful pottery called Henry II.'s ware, prevalent in the 16th century. These processes are being largely adopted in Prussia. In the architectural court of the Great Exhibition were specimens of tiles manufactured on the dry method by Mr. Minton, in imitation of *terra-cotta* stone. The introduction of such ornamental works instead of carved stone, is a great point as it respects economy. The manufacture of terra-cotta, or baked clay resembling stone, is likely to become an important branch of industry in England, if the material can be made to resist the climate, and brave the effects of frost. The clay requires to be fired to the point at which the cohesion of the particles exceeds the expansive power of water when frozen. When the clay used cannot itself be made to acquire that power, some calcareous clay, or some vitreous material is added, in due proportion. In Vienna some of the finest buildings are wholly ornamented in terra-cotta, and there is no doubt of its adoption here, if it should be found sufficiently durable.

Fig. 1711.

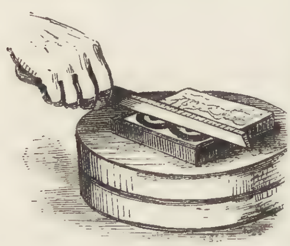


Fig. 1712.

Section VII.—Firing.

The vessels and other articles produced by throwing, pressing, and other processes, described in the last section, are raised to a very high temperature, whereby they lose their friability, and acquire solidity and density. Some of the admired wares of different nations have not been fired, but simply baked by exposure to the sun. Such are the bricks of many parts of Asia and Africa, Etruscan vases, and similar articles intended to decorate houses or to form part of the furniture of tombs.

The temperature at which ceramic wares are fired has a great influence on their character and texture. The usual effect of firing is to convert the article into a hard sonorous *biscuit*, more or less porous, and requiring the application of glaze and a second firing in order to remove the porosity and give a durable smooth surface not very liable to tarnish. In the case of porcelain, the temperature of the first firing is sufficient for incipient vitrification, so that, as far as use is concerned, the article is complete at one firing; the second firing being for the purpose of fixing enamel ornaments, &c. The firing of ceramic wares is a costly process, on account of the great expenditure of time and fuel. It was, therefore, a great improvement when Wedgwood introduced a ware so compounded that partial vitrification took place at the first firing, thus rendering a second unnecessary. The Lambeth potters, also, by the ingenious artifice already noticed (Sec. II.) of throwing salt into the kiln at a certain stage of the firing, manage to fire and glaze certain coarse wares at one process.

The arrangement of the kiln for firing ceramic wares varies with the nature of the wares themselves and the kind of fuel employed. Fig. 1713 represents a section of the pottery kiln. It is a massive cylinder

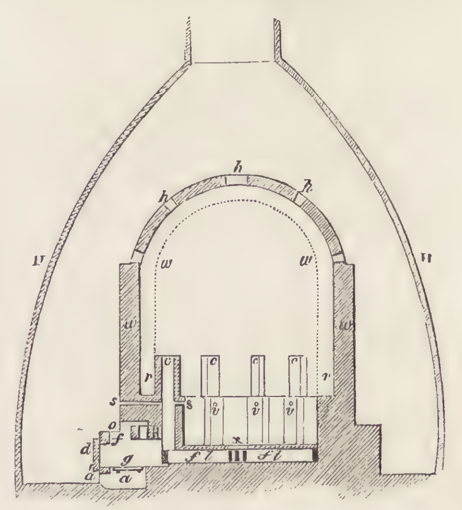


Fig. 1713.

of brickwork *w w*, bound with iron bands, and surmounted by a dome, with apertures *h h* in the top to allow of the exit of smoke. These apertures are immediately under the chimney of an outer hovel H, which protects the kiln from the cooling effect of air and rain, and also assists in carrying off the smoke. The kiln is heated by 6 or 8 fire-places placed

equidistantly round the cylinder. One of them is shown in the section. *f* is the fire, *g* the grate, *a* the ash-pit, *d* the fire-door: the draught is regulated by enlarging or contracting the openings *o* and *a'*. Between the wall *w* and the chimney *c* is a space *r*, about 15 inches wide, and $3\frac{1}{2}$ feet above the floor of the kiln: below this floor are flues *f l* for the circulation of the flame: these flues all meet in the centre *x*: at *c c* are vertical flues, and at *s v* are sight holes to allow the men to watch the behaviour of the fire, and regulate the draught of the flues *c c*.

The porcelain furnace at Sèvres, in which wood is the fuel, is a sort of triple kiln K K′ K″, Fig. 1714. A

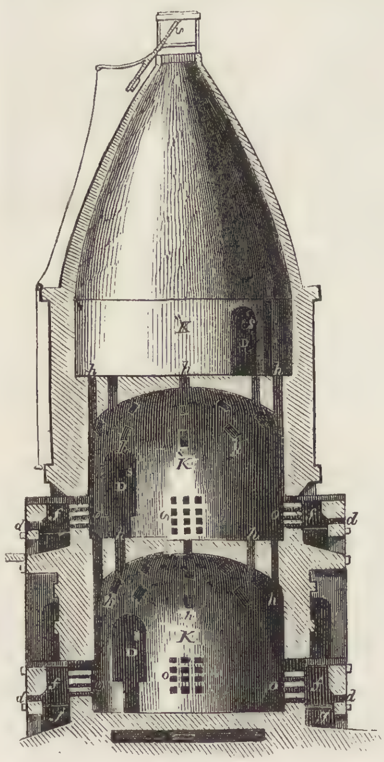


Fig. 1714.

very elevated temperature is obtained in K K′, suffisient for baking the porcelain: the temperature in K″ suffices for the glazing and enamel colours. Each of the first two kilns is heated by 4 exterior fires *ff*, with downward draughts. Each fire is contained in a rectangular fire-place *f*, with a grate *g*, and an ash-pit below, which, together with the stoke-hole *a*, admit of being closed from the outside. The flame enters the kiln by a number of square openings *o o* in the wall. When the porcelain is arranged in the kiln a quantity of small live coal is put upon the grates, and on this small cleft wood. The fire and ash-pit door being closed, the kilns act the part of a chimney and begin to draw. The air enters by the opening above *f*, and the flame thus made to descend enters the kilns by the openings *o*, and the flame and current of hot air pass from the lower to the upper kilns through the apertures *h* in the vaulted roofs, the products of combustion escaping at the narrow part of the cone *d*, where a damper is placed for further regulating the draught. The wood burnt is aspen and birch: coal gives too fierce a heat, and too smoky a flame, which imparts a yellow tint to the porcelain, and greatly deteriorates its value. The kiln is constructed of fire-brick, bound with iron hoops on the outside. Each kiln is furnished with a door D, which is used in charging, and is bricked up before the firing; but a number of small openings *s s* are left, which serve as sight-holes.

Porcelain and the better kinds of pottery are not exposed to the direct action of the fire, but are protected from the smoke and the injurious products of combustion by being packed, when sufficiently dry for the kiln, in coarse strong open vessels, made of Staffordshire marl, and called *seggars*. The coarser kinds of pottery are, however, differently arranged. A number of slabs of fire-clay are set up on edge, as shown in Fig. 1715, and upon these similar slabs are placed

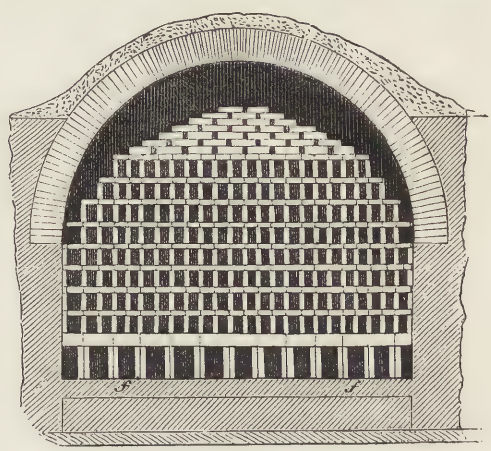


Fig. 1715.

horizontally, thus leaving a multitude of spaces in which the articles to be baked are placed during the building up of this arrangement. The flame and hot air being directed along approprate flues, penetrate all these cells and raise the articles to the required temperature. It is in such a kiln as this that articles glazed by means of salt are fired.

The seggars or cases in which porcelain and the finer kinds of pottery are placed, are made of a mixture of fire-clay and old ground seggars. They are of various shapes and sizes, according to the kind of articles which they have to contain. They are made by well kneading the material, rolling it out, and moulding it upon a box or shape of wood. They are first set to dry on shelves arranged round the interior of the hovel or hood H, Fig. 1713, and they are baked in the inner space *r r* of the same kiln. If the seggars are carefully prepared and of good materials, they admit of being employed many times in the kiln. Considerable skill is required in packing the articles in the seggars, so as to economise space and afford them the full benefit of the fire. If the articles to be baked are not likely to soften or vitrify under

the action of the fire, or if the glaze is not yet put on, they may be placed in the seggars in contact, so as mutually to support each other, care of course being taken that the lower pieces be not distorted by the weight of the upper ones. In this way the pieces may be made to support each other and prevent distortion. Pieces of large form or complicated shape may even require supports to prevent them from warping. The supports are of fire-clay, and exactly fit the parts supported; or if the article be very thin, it may require support, as in Fig. 1716, to prevent warping. For some kinds of porcelain a quantity of sand or powdered flint is interposed between the pieces. Saucers are kept in form by an earthenware ring, called a *saucer setter ring:* cups have also a ring of earthenware on the top of each to prevent their touching. Figs. 1717, 1718, show the method of packing vessels of similar form in the seggars. ss, Fig. 1717, shows the section of the seggars, and *c c* a ring of clay to make them tight; *p p* are projections for supporting a vessel of fire-clay, *ss*, in which the bowl, also shown in section, securely stands. Cups are also sometimes arranged as in Fig. 1718, in which the projection *p p* serves to support a ring *c* for supporting the edge of the cup, while the handle *h* passes through a space cut out of the ring, and the base *b* occupies the internal cavity of the ring. The seggars, when filled, are conveyed to the furnace and piled up, so that the flat bottom of one seggar becomes the cover to the one beneath it; but to prevent the entrance of smoke, a ring of soft clay is placed on the upper rim of each. Care is also taken so to arrange the seggars that the largest and coarsest articles shall receive the greatest amount of heat. About 30,000 pieces of ware are included in one baking. Fig. 1719 represents a porcelain kiln in the act of being filled, and Fig. 1720 the arrangement of the seggars, some of them in section for the purpose of showing the enclosed pieces. The flame enters the kiln by the openings *f f*, and is prevented from playing directly upon the seggars by a screen or guard of fire-clay *p p*. The *bungs* or piles of seggars B B, are steadied by means of short struts. P shows the method of arranging a large porcelain slab for firing.

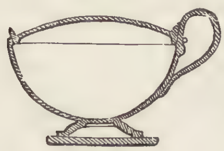


Fig. 1716.

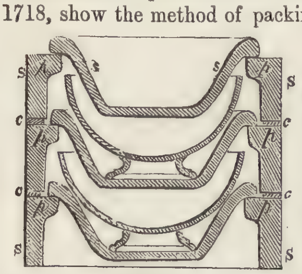


Fig. 1717.

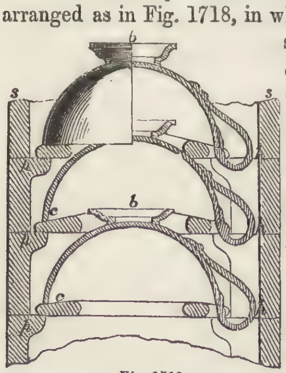


Fig. 1718.

The kiln, when filled, is bricked up at the door, the fires are lighted, and for from 33 to 40 hours the baking goes on under the watchful care of experienced men. The fire is usually lighted in the evening, kept up with considerable force all night, the flames issuing from the chimney, and early in the morning the *first watch* is taken out to see how the baking goes on. These watches, or trial-pieces, are rings, shown in Fig. 1721, made of fire-clay, which changes colour with the temperature. A number of them are so placed in the kiln that the fireman can insert a long iron rod and draw out one of the rings at pleasure, and by the appearance of this he is able to judge of the heat of the kiln, and increase or lower it as he thinks needful. When the trial-pieces convince him that the baking has continued long enough, the fire is allowed to go out, and the contents of the kiln are left to cool gradually for 24 hours or upwards. The quantity of coals consumed in one baking is about 14 tons.

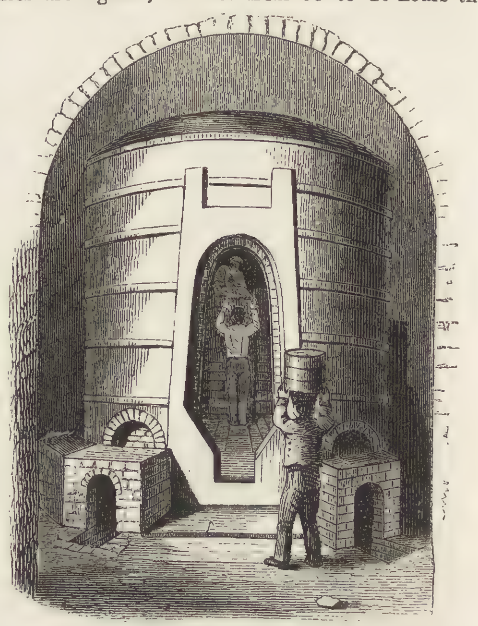


Fig. 1719.

Fig. 1720.

With respect to the whole process of firing, and to this large consumption of coal, M. Arnoux throws out a valuable suggestion, and thinks he can foresee

the time when the ware will be fired with gas, with a precision and ease which cannot be afforded by the present system. "In our present method," he remarks, "I do not think we use more than two-thirds of the heat which might be given by the fuel, whether owing to the insufficiency of draught, to the heat appropriated by a large number of exterior feeders, or because at the end of the firing these mouths are full of coal which has not produced all its useful effect. It would seem easy to accomplish the same firing by combustible gases prepared in or out of the factory, and applying all their heat in the inside of the oven. You could understand my idea by supposing established on the coal-mines an apparatus which will at once effect the distillation of the coal, and the conversion of the coke into oxide of carbon. The result would be a gaseous mixture highly combustible, which could be supplied to the factories by means of large pipes. The manufacturer would have only to mix these gases with the quantity of air he would require, according to the nature of the pottery to be fired. In the present state of science, I do not think it altogether utopian to hope that we may be enabled to purchase, from a common reservoir, the heat or the electricity that we shall want for our domestic or manufacturing purposes, just in the same way as we are now purchasing our light."

Section VIII.—Glazing and Printing.

The ware as it comes from the kiln is called *biscuit*, not because it has been *twice cooked* or baked, as the name implies, but from its resemblance to well-baked ship-bread. Wine-coolers and other porous vessels are finished in this state, but the great proportion of articles, after careful examination, have to be finished by simple glazing, or they have to be printed, painted, or ornamented in some way, previous to the glazing. In either case the glaze consists of the ingredients of some kind of glass fritted or melted together in a furnace, and when cold, reduced to powder. This powder being stirred up in water, the articles in biscuit are dipped into it, the effect of which is to cover their surface with an equable layer of the powder, and on passing them through the *glaze* or *gloss-oven*, the powder melts into a glass, which forms the ordinary surface of pottery ware. The patterns and coloured figures are put on while the ware is in the biscuit state. The addition of the glaze, which is a white opaque powder, entirely conceals the patterns, &c., but the effect of the second firing being to convert this powder into a transparent glass, the pattern is seen through the glaze.

But as every kind of ware is not ornamented with a coloured pattern, and as all glazes are not transparent, it is desirable first to inquire a little more minutely into the composition and nature of glazes.

The pottery of certain rude nations, (that of Peru for example,) is rendered impermeable by water, by rubbing it while hot with tallow, which being partly charred, fills up the pores, and gives the ware a black colour. Even the refined Etruscan and Greek vases are covered with a black carbonaceous non-vitreous varnish, which wears off in the handling: this may probably have been produced by a similar process. Wine and oil jars are rendered water-tight in Spain and Italy by rubbing them with wax: an ancient practice still followed.

M. Brongniart distinguishes three kinds of glazes, viz. *vernis*, *émail*, and *couverte*, for which we have no equivalent terms; for although we may translate the first into *varnish*, the second into *enamel*, and the third into *cover*, yet our potters only recognise the single term glaze. The ornamentation of porcelain is more akin to enamel-painting than to glazing, and as such we shall notice it hereafter.

The first glaze or *vernis*, refers to those common transparent lead glasses, which fuse at a much lower temperature than is used in baking the ware: such are the glazes for the various kinds of pottery. In the *émail* or *enamel*, tin takes the place of lead; it is opaque, and is used for majolica and other kinds of fine pottery. The *couverte* is a glass with an earthy base, and fuses at a temperature equal to that at which the ware is fired. This kind of glaze is used for hard porcelain, and certain descriptions of pottery.

The object of these glazes is to render the ware impermeable to liquids; to give it an agreeable durable lustre, and to preserve the colours and patterns which have been imparted to it. The glaze should not have too strong an affinity for the paste, or in the second firing it will sink into it, and combine so completely with it, as to disappear from the surface. The glaze must adhere so firmly to the ware, and expand and contract with it in the same proportion, as not to be liable to *craze*, crack, or scale, on being exposed to sudden changes of temperature. This crazing of the glaze is a great evil, for the cracks by their capillary attraction absorb fluids which come in contact with them, and if these fluids are of an oleaginous or fatty nature, they cannot be got rid of by ordinary washing, and soon give an ill odour, and a black appearance to the ware, and greatly promote the scaling off of the glaze. There are also fatal objections to lead glazes: they not only injure the health of the persons engaged in the glazing department of the pottery, but the persons using the ware are liable to be seriously affected by this poisonous metal, which is readily dissolved out of the glaze by means of vinegar and acid substances, which are of common use as articles of food.

The ingredients of glazes are very various. The felspars and certain volcanic scoriæ are used where the point of fusion is required to be high. A second class of non-metallic glazes includes common salt, potash, boracic acid, phosphate of lime, and sulphate of baryta. A third class of glazes consists of earthy and metallic substances simply mixed together, or fritted into a glass. These are silica, and lead, or the enamels of silica, tin, and lead. A fourth class includes pure metallic oxides, or sulphurets; such as oxide of lead in the form of litharge or minium, oxide of manganese, oxide of copper, &c. The substances in the third and fourth classes, if not previously fritted, form a glass at the expense of the

silica of the paste which they are intended to cover; but such glass is usually soft, and yields readily to the action of acid and fatty substances.

Glazes are also distinguished as *transparent*, *opaque*, and *coloured*, according to the kind of ware to which they are applied. If the paste is of a pure white, or even coloured, provided the colour be agreeable, a transparent glaze will exalt its beauty; but if the paste is not of a good colour, an agreeable effect may be imparted by means of opaque glazes, or even, previous to the firing, by dipping the article, in the green state, immediately after it has been turned, into a slip made of a superior kind of clay, a species of veneering which has been practised with much success. By this process, an article thrown with a clay of a disagreeable red colour, but with otherwise excellent properties, may be afterwards veneered on the inside with a beautiful white paste, and on the outside with a paste coloured according to the taste of the artist. Such an article may then be finished with a transparent glaze. Transparent glazes are, as already stated, true glasses. Opacity is given by means of oxide of tin, and probably also in some cases by phosphate of lime. Colour is produced in glazes by the oxides of manganese, of copper, and of iron: or, by the introduction of these oxides, together with those of cobalt and of chromium, into vitreous, opaque, or semi-transparent glazes.

As the number of pieces to be glazed at one time is usually very considerable, the glaze must be applied by some effectual but expeditious method. For this purpose, the glaze, reduced to fine powder, is mixed up with water, with the addition of some vinegar, which is said to prevent the too rapid subsidence of the powder, and the piece of biscuit ware is plunged below the surface; the porous article rapidly absorbs the water, and in doing so drags in as it were, and attaches to itself, that portion of the powder which was suspended in the water absorbed. If this simple operation be performed with address, and only the proper time allowed for immersion, the biscuit will be equally and properly coated with the glaze powder, except at those points where the piece was held during the plunging, and these are afterwards coated by means of a camel's-hair brush. The glaze is also removed with a knife and a piece of felt from those parts which do not require it, such as the bottoms of feet, necks adapted to the reception of covers, &c. In applying glazes, the hands of the workpeople must be entirely free from grease, or the glaze-powder will not attach itself to those parts which are greasy. Indeed, advantage is sometimes taken of this property to perserve certain parts dull, such as delicate ornaments, &c., by touching them with a little oil or a piece of fat, either of which acts as a *resist*. A mixture of wax and fat melted together is sometimes put on with a hair pencil, in order to give precision to the unglazed portion. Those parts of the piece which require less glaze than the rest, may have a portion of the glaze removed by gentle friction with a brush.

There are certain kinds of pottery-ware which, for the sake of economy, are passed through the fire only once, and as pottery-ware in its green state is non-absorbent, as is also the case with soft porcelain, the glaze cannot be put on by immersion. The glazing powder is mixed up with water to the consistence of cream, and poured from a small vessel upon the piece to be glazed, which is kept in constant motion, so as to distribute the glaze equally over every portion of its surface. In some of the coarse pottery made at Lambeth, of the yellowish-brown clay from Deptford, (used without any admixture, or if too fat or tenacious for certain purposes, brought down to the proper state by admixture with loam,) the glaze is put on with a brush; but for small articles, such as pipkins, which are glazed on the inside only, a little of the creamy mixture of glaze is poured in, and then poured out again, a sufficient quantity adhering to the surface by this process. The stone ware made at Lambeth from a mixture of pipe-clay from Dorsetshire and Devonshire, calcined and ground flint, presents certain peculiarities in the glazing. Custom requires that the tops or bottoms of jars, and some other vessels of this ware, shall be of a deeper brown than the natural colour of the materials affords: they are therefore dipped, as far as is required, in a mixture of red ochre and clay slip. When dry, they are piled in the furnace, with pieces of well-sanded clay between the articles to prevent them from adhering. A slow fire is kept up for 12 to 24 hours, according to the thickness of the ware, capable of raising it to a low red heat. The fire is then raised until the flame and the ware are of the same colour: this is continued for some hours, during which the glaze is added by pouring down the holes in the top of the kiln some ladlefuls of common salt, the soda of which, as already explained, forms a very thin but perfect glaze, sufficient to render this compact ware capable of resisting the percolation of water and strong acids. Large vessels of this ware are now made for the manufacturing chemists, who use it instead of green glass for distillatory vessels, Woulfe's bottles, &c., some enormous specimens of which were shown in the Great Exhibition. Pickling jars, and other vessels, in which acid substances are kept, and also those earthern vessels in which great strength is required, are made of stone-ware. The common pottery or *delft-ware*,[1] is also fabricated at Lambeth of the calcareous clay or marl, of a blue, red, or yellow colour, from the neighbourhood of Maidstone. The ware, formed in the usual way, is converted into biscuit, which is glazed in the following manner, as described by Mr. Aikin:[2] Kelp and Woolwich sand are calcined together under the kiln until they combine into a spongy imperfect glass or frit: lead and tin are calcined together until they form a greyish-white powdery oxide, called by the potters *tin and lead ashes:* the frit is then ground dry, and afterwards mixed with the ashes, a little zaffre being added if a blue tint is required, and arsenic if the glaze is intended to be white. The com-

(1) So named from the town of Delft, the centre of the Dutch potteries.

(2) Illustrations of Arts and Manufactures, 1841.

position, being well mixed while dry, is put into the hottest part of the kiln, where it runs into a vitreous opaque enamel. This is ground under a heavy iron runner, and is finally mixed with water and rubbed between stones, to the consistence of cream, into which the biscuit is dipped, as already explained.

The glazes used for pottery have received a great improvement of late years in the substitution of borax or boracic acid for oxide of lead. Borax is whiter, and gives sufficient hardness to the glaze to resist the action of the knife, while it is free from the injurious effects to the workpeople, which accompany the use of lead. According to M. Arnoux, no less than 1,792,000 lbs. of borax, representing a value of 56,000*l.*, are now used in the potteries. According to the same authority, the glaze of the hard porcelain is the pegmatite, not at all decomposed, and of which some can be found which will alone give a good glaze. At Limoges the glaze does not contain other materials. If manufacturers possess only felspar they must add some quartz, but such compounds are never so good as those found in nature; they have to harmonize the glaze with the body by mixing some portion of the latter with it, Thus, in hard porcelain there is only one hard body, surrounded by a softer one, melted one upon the other at a very high temperature. In Germany they do not use the felspar at all: quartz is combined with lime, and harmonized by a certain quantity of the body. The result is, in fact, the same; instead of having as the former a silicate of potash predominating, it is the silicate of lime. These glazes are very bright, but greyish, and less transparent than the others. The glaze of soft porcelain is wholly different, being a sort of glass, melted previously in a reverberatory furnace, ground afterwards, and mixed with oxide of lead or earthy materials. It is generally a complex compound, always based on the property of borax or oxides of lead to be vitrified into colourless glass at a low temperature. But as it would be too soft and liable to *craze*, it is hardened with siliceous materials, such as flint, felspar, or Cornish stone; and generally some carbonate of lime is added. The soft porcelain requires two firings, one for biscuit, the second for the glaze, at a much lower heat. For the hard porcelain a single firing is used at a very high temperature.

The pieces are preserved from the direct action of the fire in the *glaze* or *gloss-oven* by being packed in seggars, as in the kiln. Care, however, is required to prevent the contact of the pieces either with each other, or with the seggar, or the glaze in a state of fusion would adhere. In piling up the pieces in the seggar, they are separated by means of pointed supports and rests, which are known by such names as *cockspurs*, *stilts*, *triangles*, &c., some of which are shown in Fig. 1721; and the method of arranging flat pieces in the seggar is represented in Fig. 1722. The seggars are piled up in the glaze-kiln as in the biscuit-kiln: the temperature is raised so as just to fuse the glaze into a transparent glass and to enable it to unite perfectly with the surfaces of the biscuit. Watches, or rings of clay covered with glaze, shown in Fig. 1721, are drawn out from time to time to enable the workman to ascertain the state of the furnace.

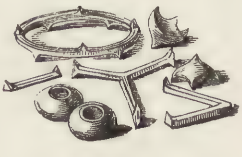


Fig. 1721.

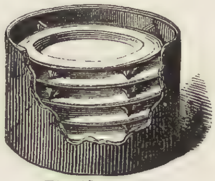


Fig. 1722.

When the ware is to be ornamented with a pattern, this is generally added before the glazing. For example,—for printing the blue pattern of a common dinner-plate, a mixture of oxide of cobalt, ground-flint, and sulphate of baryta, (fritted and ground,) is blended with a flux of ground flint and thick glass powder, which serves to fix the colour. The vehicle for making this preparation into a viscid kind of printer's ink, is a composition formed of boiled linseed oil, resin tar, and oil of amber. The colour thus mixed becomes sufficiently liquid for use by spreading it out upon a hot iron plate. From this the colour is transferred, with a leathern muller, to engraved copper-plates also made hot, the superfluous colour being scraped off with a pallet knife, and the surface cleaned with a dossil. The workman then takes a sheet of yellow unsized paper, dips it in soapy water, and lays it moist upon the copperplate, which is then passed through a cylinder press. The paper thus receives the pattern, and is handed to a little girl, called the *cutter*, who cuts away the white unprinted portion, leaving the pattern in its separate parts. These are passed to the *transferrer*, whose business it is to transfer the pattern from the paper to the biscuit. This is done by placing the pattern with the printed side next the ware, and rubbing it in with a flannel rubber. At first this is done gently, then more forcibly, until the colour is fairly transferred. The articles thus treated are then placed in a tub of water, and gently washed with a brush to get off the paper. The moisture is driven off by the heat of an oven, and the articles are ready for glazing. In some cases the impression is taken in oil only from the engraved plate on a flexible sheet of glue, called a *paper* or *bat*, which receives enough oil to furnish two impressions to the biscuit, which

Fig. 1723. TRANSFERRING THE PATTERN.

is then dusted over with colour in a dry state. The glue can then be cleaned with a wet sponge, dried, and used over again. When the biscuit thus treated is put into the oven, the oil is driven off, and the colour sinks in, and becomes incorporated with the glaze.

Section IX.—Painting on Porcelain.

Painting on earthenware and porcelain is performed with a camel's hair-pencil, and with colours such as are used in enamel painting. These are all metallic oxides, and are ground up with substances which vitrify by heat, such as glass, nitre, and borax, in certain proportions. The painting requires to be several times retouched to give it due brilliancy. The metals employed to produce the different colours are —For purple and violet, gold may be dissolved in aqua regia, and a bar of pure tin be immersed in the solution. A precipitate is thus obtained, which is named after its inventor, the *purple precipitate of Cassius.* By dissolving the gold and the tin separately, and mingling them in different proportions, various shades of carmine, violet, and purple are produced. A red colour is obtained from the suboxide of copper Cu_2O, and also from the red oxide of iron; the latter oxide when calcined with double its weight of common salt yields a permanent red. Yellow colours are obtained from chromate of lead, sesquioxide of iron, antimoniate of potash, and also from white oxide of antimony mixed with sand and oxide of lead. The oxides of uranium and lead, when mixed, produce straw colour. Blue is furnished by oxide of cobalt, also in great variety from the oxides of tin and zinc in different proportions. Green is obtained from oxide of copper, from oxide of chromium, and from different mixtures of Prussian blue and chromate of lead. Various shades of yellow green are made by the addition to the preceding of the oxides of antimony and of lead. A brown tint is given to the green by the sesquioxides of iron, and of manganese; blue, by oxide of cobalt. To produce black, oxide of manganese is employed, or several oxides may be mixed to form the colour. Pure white is supplied by one part virgin tin, and two parts common salt. M. Salvétat[1] has recently proposed some new combination of metals for painting on porcelain. According to him, a fine toned grey, superior to any other, is obtained from 1 part platinum, in powder, and 3 parts of a flux composed of minium 3 parts, sand 1 part, melted borax ½ a part. He states, as a general proposition, that whenever the oxides of iron, or of cobalt, or of the cobaltate of iron or of copper, are present in small quantity with siliceous matter, capable of fusing at the temperature to which the mixture is exposed, the colour of the multiple compound is black; that on the reactions which ensue depend the formation of the various greys and blacks, the tones of which may be varied by varying the respective proportions of the oxides of cobalt, iron, and zinc, and augmenting the proportion of the flux. The blues prepared with oxides of cobalt and of zinc are lively in proportion as the oxides contain less oxide of iron. The reds from oxide of iron, or oxides of iron and zinc, are purer in proportion as such oxides are free from foreign matters, such as manganese and copper. The platinum grey above noticed is very useful to modify the reds and ochres, and may be mixed with blues without fear of producing a black. Palladium and the other metals which accompany platinum ore may also be usefully employed. Palladium grey is paler, and ruthenium grey is redder, than platinum grey. The sesquioxide of iridium is superior to all other blacks, except the platinum.

The colours are pounded, and then ground with a small quantity of oil on a glazed palette firmly bedded in plaster on a wooden frame. Oil of turpentine, or of lavender, is the usual vehicle for the colour and the flux, the proportions of which are carefully weighed out and ground on the palette with the volatile oil. In painting, the right arm of the artist is supported on a board projecting from the table at which he works, while his left hand holds the article to be painted. While painting, the appearance of the colours is often dingy and unpleasing, but when the heat of a moderate furnace has driven off the oil and other matters, the colours are revealed in their natural brilliancy.

The enamels used in painting on porcelain involve a number of general considerations of great interest in a chemical as well as a practical point of view. It will be seen that these enamels are vitrifiable compounds attached to the surface of the porcelain by the action of heat. They are fusible at a certain temperature, depending on the fusing point of the flux; and, as porcelain is much less fusible than glass, a higher temperature may be ventured on. Care, however, must be taken so to regulate the heat as not to change the character of the metallic oxides which form the artist's pigments, nor to destroy the general effect of the painting. When properly fired, the colours have a smooth and brilliant appearance. Some of these colours are opaque, others transparent; but transparency is rather an inconvenience than otherwise, since the white colour of the porcelain seen through them produces an enfeebling effect. But in general, the enamels used in this art have the same properties as enamels properly so called—the same hardness, the same indestructibility, a similar resistance to friction, and a power of expansion conformable to that of the substance which they are intended to cover. The colouring matters are also metallic oxides; the fluxes are silicates and borates. It is usual to combine several fluxes together, either for the sake of greater fusibility, or for obtaining the desired whiteness. It would be an advantage if the silicates used in compounding fluxes were all insoluble, such as the silicates of lime, alumina, and lead; but the necessity for having a very fusible flux at command leads to the use of alkaline silicates or borates, which are soluble. It is desirable to combine them with other matters, so as to make them as little deliquescent as possible. Lead fluxes are preferred to all others on account of their more

(1) Annales de Chimie et de Physique. 1849.

equal powers of contraction and expansion as compared with the porcelain to which they are applied.

The enamels used in this art may be arranged into two groups, viz. first, those which derive their colour from the fusion of materials simply mixed together, and secondly, those in which the colouring matter combines chemically with the flux. The fluxes for the first kind of enamels ought not to exert any chemical action on the colour; while for the second kind, the fluxes ought to form with them a true chemical solution.

The proportions in which substances capable of forming silicates are to be added must depend upon the temperature which such silicates require for their formation. The proportion of acid and of base required varies with the temperature, and if the true proportion be exceeded, the excess will remain uncombined. The tendency of the silicates to unite with the oxides increases with the temperature and with the proportion of acid contained in them. A flux will act upon an oxide at a given temperature if the acid be in excess; but it will require a higher temperature if the proportion of base be increased.

The composition of enamels depends on principles such as these. For example, at a cherry-red heat the basic silicates and borates of lead, of soda, and of potash, have but a feeble action on the metallic oxides. It is evident, therefore, that this temperature and those degrees of saturation of the bases must be chosen for enamels of the first class, in which the colouring matter is merely mixed with the flux. But for enamels of the second class, where the colouring oxides combine chemically with the flux, the latter should have an excess of acid, or as much silicic acid or boracic acid as possible, the temperature remaining the same. But if the conditions of the painting require a larger proportion of base in the enamel, the reduced proportion of acid is met by employing a higher temperature. The state of saturation above indicated for enamels of the first class fulfils the conditions required for the fluxes, both with regard to the substance to be covered and the properties which they ought to have in a good enamel painting. In enamels of the second class, the facility for supplying the deficiency of acid by temperature, and *vice versâ*, gives great latitude in varying the composition of enamels, and greater scope to the artist.

The various colouring-matters employed in the composition of enamels lead to important variations in their physical characters, chiefly as regards their dilatability; and it is only by varying the nature of the flux that enamels can be made to expand and contract within proper limits. This leads to the necessity of employing various kinds of flux.

The fusibility of enamels varies with their state of saturation; the larger the proportion of alkali, the greater the fusibility; the larger the proportion of silica, the less the fusibility. In lead enamels the yellow colour produced by the silicates of lead is in a direct ratio to the quantity of base. The hardness of enamels has the same relation to the bases as the colouring. In the borates and silicates of lead, the more the relative proportion of base is increased the less stable are the enamels. The alkaline silicates and borates, especially the former, have a tendency to separate themselves from the plumbiferous silicates and borates, which increases as the proportion of base increases. At a high temperature they even undergo decomposition, and the alkali becomes volatilised. If we descend to the degree of saturation of the bibasic silicate, the compound is so much acted on by moisture that the alkaline silicate will dissolve in cold water. For this reason potash is not employed in painting on porcelain, since, in order to render enamels sufficiently fusible, and to give them the required powers of expansion, the proportions of potash required would render the enamels very subject to change. This inconvenience is got rid of by the substitution of borate of soda, which is more fusible under the same circumstances than silicate of soda or of potash, and thus the required fusibility may be obtained without lowering too much the degree of saturation. The effect of this is to diminish the yellow tinge and the liability to change, and at the same time to increase the hardness.

There are two methods of preparing enamels. For those of the first class a flux rich in base is selected, and in order to diminish the risk of exposure to a high temperature, the colouring matters are united with the flux by the process of porphyrisation, so that the mixture is not heated until it has been properly applied to the porcelain. No more flux is added than is required in order to give to the enamel after firing a smooth and brilliant effect. For enamels of the second class, the flux must have as large a proportion of acid as possible, and it must be present in as large a proportion as is consistent with the required intensity of colour; *thirdly*, the oxide must be free from any substance likely to interfere with its complete combination with the flux; *fourthly*, the enamel must be fused before being applied.

For enamels of the first class, the colouring matter does not always consist of a single oxide, but generally of several oxides combined, the object being to procure the colour due to their union; or to impart to one of the oxides a fixity, which it does not possess alone. So also in enamels of the second class, several oxides may be employed as well for the purpose of favouring solution as for obtaining the required colour. In enamels of the first class, two oxides are frequently combined, since the stability of the resulting compound resists the action of the flux. In enamels of the second class, two oxides are combined for a contrary reason; their union not being very stable, they are in that state of division which is favourable to complete combination with the flux. With this view, it is desirable to prepare these enamels by heating the colorific oxide with the elements of the flux, rather than with the flux previously vitrified. In such case, the oxide of lead, which is always one of the constituents, attacks the colouring oxide, reduces it to a state of minute division, dissolves it, and thus prepares it for its union with silica.

Enamels used for painting on porcelain are similar to those used for painting on glass; but they are more numerous, since porcelain admits of opaque as well as transparent enamels, being employed. Hence, in porcelain enamels of the first class, much use is made of the oxides of tin, antimony, and zinc. They have the advantage of fixing other colouring oxides, of imparting to enamels their own peculiar tints of white, and that opacity which is often useful to the painter on porcelain, but could not evidently be used on glass. For example, *clear blue*, or *azure blue*, is obtained by a mixture of oxide of zinc or of tin with oxide of cobalt. *Emerald green* by oxide of copper and antimonic acid. In these cases stannic acid, antimonic acid, and oxide of zinc soften down the blue and green by their own proper white tints. Most of the *yellows* are obtained by the antimoniate of iron, of lead, or the zincate of iron. These are cases in which the antimonic acid and the oxide of zinc are especially employed to give stability to the oxides to which they are united. The yellow enamel, coloured by chloride of silver, is used only for the purpose of lighting up or brightening the purples. Porcelain does not admit of being coloured by cementation as is the case with glass. [See Glass, Sec. IX.]

With respect to the composition and preparation of the fluxes, we must refer to the article Enamel.

Several of the metals are used in ornamenting porcelain without the intervention of a flux, or without being converted into oxides. The gold employed in gilding porcelain is first dissolved in aqua regia; the acid is driven off by heat, and the gold remains in a minutely divided form, or the gold may be precipitated by means of sulphate of iron. The gold in this pulverulent state is mixed with $\frac{1}{12}$th of its weight of oxide of bismuth with a little borax and gum-water, and applied to the edges of the ware with a pencil. Articles which have to be ornamented with a circular line only, are placed on a whirler. Fixing the article upon the circular head, the workman applies the pencil to it with one hand, kept steady by means of a rest, while with the other hand he causes the circular head to revolve. The effect is thus produced with great exactness. The articles thus ornamented appear dingy when first baked, but the lustre of the gold is brought out by burnishing, first with agate, then with blood-stone. This is done by a female, who uses the burnisher lightly and in one direction, not to scratch the gilding. The burnishers are of various forms

Fig. 1724.

and sizes, as shown in Fig. 1724, to suit the forms of the articles operated on. A little vinegar or white-lead is also used to clean the gilding. Some years ago the weekly consumption of gold for the gilding of porcelain in the borough of Stoke-upon-Trent was estimated at 650*l.* sterling, or 35,000*l.* per annum.

Metallic lustres applied to stone ware consist of metals, which, like gold, do not readily oxidize. Silver lustre is obtained from platinum, and has a silver white hue; there is also a platinum lustre resembling polished steel. For the former, the metal is dissolved in aqua regia, formed of equal parts of the acids, and the saturated solution poured into boiling water. On pouring this into a warm solution of sal-ammoniac, the metal falls down as a yellow precipitate, which is to be well washed with water, and dried. It is applied to the ware by means of a flat camel's-hair brush, after which it is passed through the muffle kiln. The operation may require to be repeated to obtain sufficient body of lustre. If the articles come out black from the kiln, friction with cotton will restore the proper colour. For the platinum steel lustre the metal is dissolved in aqua regia, composed of two parts muriatic acid, and one part nitric. When the solution is cool, there must be dropped into it, agitating all the time with a glass rod, spirit of tar, composed of equal parts tar and sulphur, boiled in linseed oil and filtered. If the platinum solution be too strong, more spirit of tar must be added; if too weak it may be concentrated by boiling. The mixture being spread over the piece, and passed through the muffle, it will assume the appearance of steel. Gold lustre is obtained by precipitating a solution of gold in aqua regia by means of ammonia. The precipitate, which is fulminating gold, is mixed while moist, with essential oil of turpentine, and it is applied to the surface of the ware without a flux. After the firing the lustre is brought out by friction with linen. The remarkable iridescent lustre, called by the French *lustre cantharide,* is obtained from chloride of silver, the partial decomposition of which is determined by combustible vapours. A mixture, made of a lead glass, a small quantity of oxide of bismuth, and chloride of silver, is applied by a camel's-hair brush to the ware, which is then heated in the muffle kiln. When at a red heat, a fuliginous smoke is introduced into the muffle, which produces the desired partial decomposition. An iron lustre may be obtained by dissolving iron or steel in muriatic acid, mixing the solution with spirit of tar, and applying it to the surface of the ware. Silver and platinum lustres are commonly laid upon a white ground; gold and copper lustres succeed best on coloured grounds. The paste body for lustrous ware is usually made on purpose, and is coated with a lead glaze composed of 60 parts litharge, 36 of felspar, and 15 of flint. The paste body is brown, and consists of 4 parts clay, 4 of flints, 4 of kaolin, and 6 of felspar.

The firing of painted porcelain is a delicate operation, and is conducted in a muffle furnace, shown in section, Fig. 1725. The heat is regulated according to the indications afforded by small watches of porcelain, painted with some of the enamel colours

employed on the ware, those being preferred which are most susceptible of change or injury, the rose colours for example; and gold lustres, &c. which require a high temperature for their adhesion. Consequently, the fire must be so regulated as to conform to these and other conditions. The porcelain must be passed twice through the fire: the first firing is rather a trial than an actual result: it enables the artist to see what is wanting in the application of the colouring oxides, &c., and having retouched the parts requiring it, it is passed a second time through the muffle. A third, or a fourth firing may even be required for large and elaborate works. The muffles are made up of tolerably good clay, supported on fire bricks, and heated from the outside.

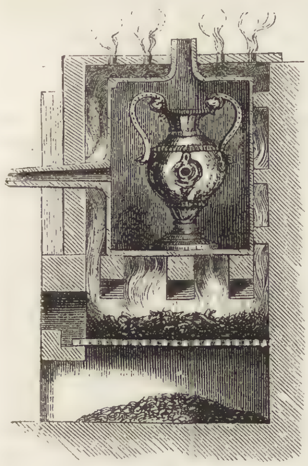


Fig. 1725.

Section X.—On Design in Pottery and Porcelain.

If it be true that "fictile fabrics alone will often mark the standard of national civilization, and indicate the progress of a people in the arts of life," then it must be felt by many a student of the pottery and porcelain displayed at the Great Exhibition, that several nations are making great and contemporaneous advance at the present day, and that Great Britain is honourably distinguished in the friendly rivalry. The general system of the porcelain manufacture has been improved, and in very many cases a better taste has been introduced in the various modes of ornamentation. Merely ornamental works in pottery and porcelain appear unsuitable, and at variance with the natural purposes of so eminently useful a material; and we suppose that few persons could persuade themselves really to admire the imitations of beautiful flowers, far less of fish, and even reptiles, which were cleverly executed in high relief in the centre of dishes and baskets, of this fragile material, and conspicuously exhibited in the foreign department. The more exact the imitation of animal life, the more unpleasing the effect; in fact, there was something monstrous in the idea of an ornamental dish, over the surface of which frogs and lizards in all their green and yellow ugliness were preparing to leap or crawl. Such instances of bad taste were not, however, frequent, although purely ornamental subjects in porcelain, most elaborately decorated, were to be found in several departments. These are defended by Mr. Redgrave, in his Report on Design, on the ground that when works are prepared simply as ornaments, they may not only be admired as addressed to the purpose of giving pleasure by their beauty, but because they often insensibly exercise a useful influence on the general taste of the manufacture. This he illustrates by referring in the following terms to that most interesting and valuable collection of porcelain in the Sèvres Court:—"Here we find the taste of the first artists, assisted by the science of able chemists, and under a judicious direction, united to the most skilful workmanship and manufacture, and the result is that the manufacture of porcelain is carried to the highest state of excellence. The greatest part of the display, however, consists of works which must be classed as ornaments, such as vases, caskets, chalices, tazzas, &c. The forms adopted are pure, and those pure forms rarely interfered with by the reliefs. The details of the decoration, the modelling of the reliefs, and the painting—whether these consist of figures, flowers, or simply of ornamental forms—are of rare and felicitous excellence in many cases, and of high merit in all. The finished perfection of these choice works must have exercised a great influence on the other manufactures of the country, not only by forming a band of workmen educated to perceive excellence as well as to produce it, and capable of giving assistance in many other branches of manufacture, but by their effect on the general cultivation of the public taste. Nor do such establishments benefit the country that supports them alone, they diffuse taste abroad, even in other lands. Thus the improvement of our own general manufacture of china has already been adverted to, and yet it is but justice to say that it owes much to the labours of the national establishments both of Sèvres and Dresden; not only that their works have in some cases served as our examples, or guided our manufactures by the principles of their decorative treatments, but from the stimulus to improvement which has resulted from the contemplation of rare works, and of that perfection which arises from a manufacture occupying itself rather upon efforts of skill than upon general production, and able to employ itself upon them irrespective of expense, and regardless of cost."

The abuses of the system of mere ornamentation, are, however, distinctly pointed out, as shown in some of the works of the Dresden manufactory. "The surface," says Mr. Redgrave, "is often covered with purely imitative flowers in high relief, glowing and brilliant as the tints of nature, yet looking gaudy as ornament, and from their filmy projections, liable to injury with every touch, and their preservation a source of constant anxiety to the possessor. Even the May-flower pattern—a production of great beauty, on the principle of a diaper of form and colour—from its minute hollows, is quite incapable of being cleansed, and from the thickness which it adds to the form, contradicts the true effect of porcelain, which should unite lightness with capacity." The skill and taste of English artists have not yet been fully exercised in reference to pottery and porcelain. Beautiful works in enamel show what they are capable of, but enamellers are not connected with the potteries;

whereas in foreign countries, where the nation pays for the best means of improving the porcelain manufactory, the services of the most skilful and eminent men are eagerly sought. "In England our china-painters are not artists, and but few of them seem to have artists' feelings, nor until of late years have they had the opportunity of gaining the necessary instruction. The painters on china copy fruit, foliage, and flowers well; but when such labours are original, they too often consist of but slight variations of some stock and stereotyped forms and colours which the workman uses over and over again, without novelty either in grouping or drawing. In the power of painting the human figure they are mostly deficient, and few of them are able to execute subjects of which flesh forms a part. The modellers have also been sadly deficient in knowledge of the figure, and of its anatomical details. In both these particulars, however, they are slowly improving, and the introduction of Parian and other materials for statuettes, which is beginning to form a large branch of business in the potteries, and which as yet is nearly peculiar to England, has been of service in showing them their defects, and in urging them to amend them."

To the above remarks, the truth and justice of which must commend themselves to every one acquainted with the subject, we would willingly add some judicious suggestions on what may be called the common sense of designs in pottery and porcelain. A single extract is all that our limits will allow of, but the whole, as contained in the Jury Report, (pp. 733, 734) is well worth the attention of manufacturers and designers. The most elegant forms in vessels of capacity must be united with the most convenient adaptation to use, and with the readiest means of cleansing; otherwise the mere elegance will not atone for daily and hourly annoyance in other respects. "It is to be remembered that the means of receiving that which is to be contained, is as necessary as its ready outpouring; since it is hardly necessary to have to apply a funnel to fill a pitcher or jug intended for constant use, although this may be permitted in a bottle, which is required to keep its contents cool, or to be carried about, and subject to spill them by jolting, and therefore needing a smaller aperture. Moreover, a jug or pitcher, which will admit the hand to cleanse it thoroughly, must be more suited to daily use than one which will not. A due consideration of utility would regulate the form in many other cases; as, for instance, in cups and other drinking vessels, it might be most graceful to curve the top edge outward, but since such a form is likely to overflow the person in drinking, however superior in elegance, it should not be adopted. When utility is considered before ornament, numerous truths of the like kind will be arrived at, which are entirely overlooked when the order is reversed; thus relief, when used, should be extremely low, and without indented hollows in the composition, as well as without undercuttings, in order to give facility for cleansing: but while this is required for utility, it is necessary for elegance and beauty also. The Greeks were fully aware of it as an important truth, and in their pottery abstained from reliefs, or kept them at the lowest impost. The vases of Etruria have generally their line unbroken by the ornament, and the reliefs on the celebrated Portland vase are so extremely low as entirely to preserve its outline." Mr. Redgrave illustrates these and similar remarks by an engraving of an antique enamelled flower vase, where taste and convenience are both consulted, and also gives a sketch of different forms of Etruscan vases, originally intended for two handles, but now used with one, to the inconvenience of the possessor, showing with how little thought adaptations of classic forms are introduced at the present day. Our own experience accords with this statement. A ewer of tall and elegant form having proved extremely inconvenient from the fact that the handle is placed too high up, (no deviation having been made from the original pattern vase, except in converting the second handle into a lip,) and thus the water cannot be poured out without the use of both hands. Mr. Redgrave justly reprobates the employment of sacred symbols as ornaments of vessels in common use, and quotes a wise remark, that "symbolical ornament demands perfect accordance between the use of an object and its decoration." This will at once condemn Scripture sentences on bread platters, figures of the apostles as ornaments for jugs and spoons, and numerous other well-meant attempts at symbolical ornament.

While there is much imperfect taste to be corrected, and much further knowledge to be acquired, yet we are undoubtedly making steady national progress.

The results of the Great Exhibition show a great advance made by England in ceramic manufactures. The classic beauty of many of the designs, and the admirable execution of the works exhibited by the firms of Minton, Copeland, Wedgwood, Ridgway, Mayer, and others, give the highest promise for the future. The great difficulty in the present state of things, when a constant and increasing demand has to be met by the labour of the potteries, is to find time for study and invention. This is well alluded to by a distinguished juror, and patron of the ceramic art. "Commerce wants rapidity of design and execution, cheapness, convenience of form, colours at the same time lasting and attractive, eternal reference to the ledger account: on the other hand, art needs, genius, education, original conception, accurate drawing, chemical science, the power of remodelling, and remedying defects and flaws, refined taste, and, above all, time and money; so is created a perpetual conflict between art and manufacture. The tendencies of the age to save labour, to lessen expense, and to multiply production, are abstractedly all adverse to the development of taste, and I often think what advantages to art would be gained, if more breathing-time could be afforded to genius, by the establishment of cities of refuge in Italy and Greece, where artistic feeling could fly for peace and repose, and perfect, under a warmer sun, the education of the student's eye, freed as he then would be from the

trammels with which he is now encumbered, working, as he too often does on his own account, for his own daily bread."[1]

POUND. See WEIGHTS and MEASURES.

POWER—MECHANICAL POWERS. See STATICS and DYNAMICS.

PRECIPITATE, a substance separated from a liquid in minute particles, which subside to the bottom of the vessel. "Precipitation is valuable as a mode of separating substances, and consists in changing them from a soluble into an insoluble state. It always depends upon altering the relation of the solvent to the substance it holds in solution; this being effected sometimes by changing the state of the solvent, as when water is added to a solution of resin in alcohol, or alcohol to a solution of gum in water; and at other times by causing a change in the body dissolved, as when sulphuric acid is added to a solution of baryta to precipitate the earth, or ammonia to a solution of iron to precipitate the oxide. It is often practised to render the presence of a substance visible, and forms an essential part of analytical and other processes, as well in the discovery of bodies, as in their separation and estimation. Any substance added to a solution to cause a separation in the solid form of matters present, has received the general name of *precipitant*, and the substance so separated is called a *precipitate*."[2]

PRESS. See HYDROSTATICS and HYDRAULICS—COINING—OILS and FATS—PRINTING—SCREW, &c.

PRINCE'S METAL (named after Prince Rupert), an alloy of copper and zinc, containing more copper than brass does, in which respect it resembles *Tombac*, *Dutch gold*, *Similor*, and PINCHBECK. See BRASS.

PRINTING. The art of printing, in its usual sense, is a mechanical process by which any piece of literary composition is multiplied by means of types, ink, and paper. The art consists essentially in the production of copies by means of pressure. This latter definition would include the taking of impressions in clay, wax, &c. by means of cameos and intaglios; and such is an example of multiplying copies by pressure only; but in printing, as it is commonly understood, an ink or pigment is always transferred from the stamp or type to the paper or other substance destined to receive the impression. The impressions or copies produced by printing are not, however, exact copies of the original stamp or type, any more than the wax impression of a seal is a copy of the seal which produced it. Simple as this fact may appear, it nevertheless constitutes one of the chief difficulties in the art of printing and engraving. The raised surface of the stamp or type is sunk in the copy, and its form is also reversed; that is, all those parts which are on the right-hand in the stamp, are on the left-hand in the copy, thus requiring that in setting up the type all the lines shall begin on the right-hand of the page, in order that they may commence on the left-hand in the printed copy. Of the various kinds of printing, the most common, as well as important, is *letter-press printing*, in which impressions are taken from letters and characters cast in relief in separate pieces of metal. Wood engravings are also cut in relief, and they print in the same way as moveable types. *Copper-plate printing* is the reverse of letter-press: the characters are sunk or engraved in intaglio, and the pigments or inks are contained in the lines of the engraving, below the general surface. Hence, while in letter-press printing the letters or lines are pressed into the paper, in copper-plate engraving the paper is forced into the lines or letters of the copper-plate. There is yet a third mode, called *surface-printing*, of which *lithography* and *zincography* are examples, in which the lines or letters are written or drawn on the surface with pencils of a peculiar kind, the marks produced by which will take up the ink from an inked roller passed over them, while the ground on which the letters are written refuses to combine with the ink. [See ENGRAVING.] Calico is printed from surfaces engraved in relief or in intaglio. [See CALICO-PRINTING.] In the present article our attention will be directed to letter-press printing.

SECTION I.—HISTORICAL NOTICE OF PRINTING.

It must surely be regarded as an astonishing circumstance, that an art so admirably calculated to advance the true interests of mankind, and yet so simple in its essential characteristics, should have been discovered at so late a period as the middle of the fifteenth century. It is impossible to say when the germs of the art did not exist. A man could not walk along the sands of the sea-shore without multiplying the impressions of his footsteps. Seals and signets are repeatedly mentioned in the Old Testament, and were in common use among all the civilized nations of antiquity. The Assyrians printed inscriptions on the clay which had been moulded for the bricks employed for building, and the Romans were accustomed to stamp inscriptions on pigs of lead and other articles of their manufacture. The Chinese method of printing, as practised from a very remote period, would seem to require only to be known to a nation possessing an alphabet, in order at once to suggest the art of printing with separate pieces of metal capable of unlimited combination. According to the Chinese method, smooth blocks, of a firm close-grained wood, were reduced to the size and form of the page of the intended book, and on one side was glued a piece of paper on which some able penman had transcribed the words intended to be engraved. An engraver then cut out the characters in relief, and the remains of the paper being rubbed off, the engraved tablet was ready for printing. Thus in printing a book there were required as many blocks as there were pages, and as no block could be used in printing other books, the process was tedious and expensive. It had its advantages, however, in requiring no correction of the press; and forming, as it did, a kind of direct stereotyping, a portion of an impression could be worked off as it was wanted. The books thus

(1) Lecture delivered in January 1853, by C. B. Wall, Esq. M.P. before the Literary and Scientific Society of Salisbury.

(2) Faraday. Chemical Manipulation.

produced are said to be accurate and beautiful, but not durable, on account of the bad quality of the paper and ink employed.

It is remarkable that the first essay in printing in Europe was by means of blocks such as these; but there is not sufficient ground for the belief that the idea was suggested by the Chinese. It appears that about the year 1400 playing cards and manuals of popular devotion, which had previously been manufactured by hand, were now produced by means of block-printing. The manuals, like the cards, mostly consisted of a single page, but sometimes of several pages. The era of these *block-prints* and *block-books*, as they are called, was the first half of the fifteenth century; and during the time that they were in common use, the idea probably occurred to many ingenious minds of cutting up one of these blocks so as to have separate letters for new combinations of words and sentences. Indeed, this separation of the letters had already been done for the eye in the common *horn-book*, or A-B-C-book, from which children learned their letters. And the execution of such an idea has actually been claimed by the Dutch, for one of their countrymen, Lawrence Coster, of Haerlem, who is said, about the year 1430, to have printed by means of "separate moveable wooden types fastened together by threads," and that "his press was shaped like the common wine-presses." He is reported to have kept his art secret for about ten years, when, in 1440, one of his servants stole his types and the necessary apparatus, and after having visited Amsterdam and Cologne, settled at Mentz as a printer. These details, however gratifying they may be to national vanity, rest on a very slender foundation; but even supposing that Coster did print with moveable wooden types, he was far from having produced the art of printing in its useful practical form, for that requires the production of metal types by the cheap and rapid method of casting; but types cannot be cast without a matrix or mould, and a mould cannot be formed without a punch or stamp of hardened steel; so that if it be admitted that Coster succeeded in printing with moveable types of wood, then that worthy triad Gutenberg, Fust, and Schöffer, whose story is briefly given in our article ENGRAVING, can only claim the honour of having improved the art; but they are improvers of such a character, that they bear to the art of printing the same relation that Watt bears to the steam-engine. We are, however, on a careful examination of the confused mass of evidence before us, disposed to reject the claims of Coster and to admit those of Gutenberg, Fust, and Schöffer, in the order in which we have written them down. Coster is said to have imagined the art from having engraved certain letters and words on the bark of trees during his afternoon walks, and having filled up these engraved letters with a viscid kind of ink, he found he could take impressions on paper from them, and that in this way he actually printed lines and couplets for the benefit of his friends. This process is certainly a step in the rear,—for with the full knowledge of the art of printing with blocks and of common engraving, why should he adopt the very rude method of printing from the bark of trees? and, moreover, if it were his fancy to mutilate the trees which adorned his path by carving words upon them, he must have arranged the letters the reverse way, or they would be of no use to the reader when printed. Then, again, when he had perfected his art, and was practising it for profit, the books which he produced must have excited the admiration of the learned, if not by their beauty, at least by the extraordinary facility and cheapness of their production; but this is nowhere stated, and it is not even pretended that a single copy of any one of Coster's books is in existence; whereas Gutenberg, Fust, and Schöffer, have left abundant evidence of the genius and industry with which they have benefited mankind. Then with regard to the robbery by Coster's servant, there is some mystification about the name of the thief. He is referred to as Jan ——; and some writers who advocate the claims of Holland, have had the audacity to fill up the blank first with the name of Gutenberg and then with that of Fust. Gutenberg was a gentleman, who expended the whole of his private fortune in endeavouring to perfect the art, and Fust was a goldsmith; both men of consideration in the town where they resided. It is stated that Coster had such a demand for his books, that he kept two or three men constantly at work; that while he and his family were at their devotions on Christmas Eve, 1440, this Jan —— ran off with his types, &c. It seems to have escaped the notice of Coster's advocates, that 1440 is the year in which all writers agree that Coster died at the age of 70: but supposing it to be true, as some have asserted, that Coster died broken-hearted at the loss of his types, is it not remarkable that within one year of the robbery we should hear of the thief, still nameless, being settled quietly at Mentz, and producing works of repute, the titles of which are given, with the identical letters which he stole from Coster, and yet that Coster in ten years should have produced nothing with the said types, at least nothing which has reached us, not even a title, except the *Spiegal enser Behoudenisse*, of which it is doubted whether blocks or moveable types were used in its production? We may now dismiss this claim with the remark, that it was not made until about the year 1568, or 128 years after Coster's death, when it was brought forward by the historian Adrian Young, or, as it is pedantically rendered, Hadrianus Junius, who had heard it from his tutor, Nicholas Galius, who had heard it from a book-binder, who had worked for Coster.

Of a very different character are the claims of Gutenberg and his companions. Gutenberg, surnamed Genzfleisch, Gensfleisch, Gensefleisch von Solgenloch, was a native of Mentz (or *Mayence*, as we write it, after the French fashion of changing all proper names), and of noble family. He is said to have resided for some years at Strasbourg, where he practised the art of printing with moveable types, which he endeavoured to keep secret. About the year 1450, he returned to his native city, where he sought the aid of John Fust, a wealthy goldsmith,

with whom he entered into partnership: he hired a house, and took into his employment Peter Schöffer and others. Schöffer appears to have been a scribe, one of that valuable class who produced books of great beauty by the costly and tedious process of transcribing. He was now engaged in a pursuit which, if successful, would annihilate his profession. In lending his aid to the new undertaking, he knew what was required by learned men, namely, books produced with increased facility and economy, but not so different in style and appearance from those already in use as to shock the conservatism of the age by too startling a novelty. Fust, as a worker in metals, would be able to bring all the resources of his trade to bear upon what we may fairly conceive to have been Gutenberg's leading idea, viz. the production of moveable types in metal. In his earlier efforts at Strasbourg, Gutenberg formed his types by carving or chasing them out of separate pieces of wood or metal; but one of the first results of the partnership was to cast the types in moulds of plaster, and finish them off by hand. But the plaster was too soft a material for the purpose, and the hand-labour slow and costly, for an ordinary mechanic could not be put upon such delicate work. As a stimulus to invention, Fust is said to have promised his daughter in marriage to Schöffer, on condition of his perfecting the invention; and the result was the cutting of metal punches and the formation of matrices, thus giving to the art all its essential elements. The works which were issued from their press, numerous copies of which still remain, are remarkable for taste and beauty, and eminently justify the claim of these three distinguished men to the honour of having invented the art of printing with moveable metal types, produced by casting in metal moulds formed with steel punches. After working together for some time, the partners disagreed, and went to law; and we learn from legal documents that Gutenberg had expended the whole of his considerable private fortune in his experiments, and had mortgaged his printing materials to Fust. In 1465, he abandoned the art which had proved so ruinous to him, and entered the service of the elector, Adolphus of Nassau. He died February 24th, 1468. His printing-office and materials had by this time passed into the hands of Conrad Humery, Syndic of Mentz, who sold them to Nicholas Bechtermunze of Elfried.

Within eighteen months of the dissolution of partnership, viz. in August, 1457, Fust and Schöffer produced the celebrated *Psalter*, printed with large cut type. This is the first book that bears the name of the place where it was printed, the name of the printers, and the date of the printing. In 1460 was printed the celebrated Latin *Bible*. Fust died at Paris in 1466, where, in consequence of selling his books in such abundance, and at a rate so very much below that of the transcribers, he is said to have been accused of calling in the aid of the enemy of mankind to assist in this rapid production. Hence arose the story of the Devil and Dr. Faustus—a curious partnership truly, considering that the works produced by this firm were Bibles and Prayer-books! Schöffer survived his father-in-law many years, and, in conjunction with Conrad Henlif, produced a great number of works, which, with those previously produced, exceed fifty in number. Henlif's name is in the colophon of the fourth edition of the Bible of 1502.

The capture of Mentz, by Count Adolphus, of Nassau, in 1462, interrupted the labours of Fust and Schöffer, and probably compelled a number of workmen initiated in the mysteries of the art to seek refuge in neighbouring states, and thus to diffuse a knowledge of its practice. It had already acquired such fame that every person in Europe pretending to literary skill sought for information respecting it. The eagerness with which the new art was welcomed and adopted, in days, too, when the march of improvement was very slow, may be judged of from the fact that, within six years of the publication of the Psalter, the art had extended to several cities which were in connexion with Mentz, and within fifteen years to every considerable town of christian Europe. This rapid progress is to be attributed not a little to the fact that the works of nearly all the early printers were devoted to religion or learning, whereby the new art was raised in the estimation of all men. When the art was introduced into England it was first practised in a chapel near Westminster Abbey, a circumstance which has been perpetuated by the technical application of the word *chapel* to every printing-office to this day; and when the men meet together for the purpose of considering or framing rules and regulations for the good order of the printing-office, they are said " to hold a chapel."

Caxton was the first English printer. It is asserted that, during his residence in the Low Countries, he secured the services of one of the fugitive printers of Mentz, and established a printing-office at Cologne, where he made the acquaintance of Wynkyn de Worde, Theodorick Rood, and of his countryman, Thomas Hunte, who all afterwards became printers in England, the first-mentioned accompanying Caxton to England when he removed his printing materials from Cologne. The first book that was printed by Caxton on his arrival was the *Game of Chess*, which was completed on the last day of March, 1474. In the work which preceded this—the printing of which was finished at Cologne—Caxton takes care to explain to his readers that the work is *printed*, " not wreton with penne and inke, as other bokes ben, to thende that euery man may have them attones (at once), ffor all the books of this story, named the Recule of the historyes of Troyes, thus enprynted as ye here see, were begonne in oon day and also fynished in oon day."

We get some idea of the early printing-presses from a device of Badius Ascensius, of Lyons, 1495—1535, inserted on the title-pages of his books in various sizes. It appears that this press could only print foui pages at a time, and that at two pulls. The table and the tympan ran in, and the plattin was brought down by a powerful screw by means of a lever inserted in the spindle.

The colour of the ink in the early printed books varied considerably. The earliest copies of the *Speculum* and the *Biblia Pauperum* were printed in ink of a brown colour, of which raw umber is the principal ingredient. This colour harmonized better than black with the adornments which were afterwards added by the illuminators. Fust and Schöffer introduced black ink, and must have been skilful in compounding it, since their works still possess depth and richness of colour. The same colophons which give representations of the presses show the method of applying the ink to the types by balls of skin stuffed with wool, a plan which continued in use up to within a few years. The ink was laid in some thickness on the corner of a stone slab, and thence taken in small portions, ground with a muller, and so taken up by the balls and applied to the type. The types were disposed in cases similar to ours, but the composing-stick was somewhat different. In the early pictures of printing-offices pictorial effect is studied rather than propriety of arrangement; for in one room are represented the operations of casting the type, composing, reading, and working, operations which would evidently be distributed in different rooms. The early printers were too careful to preserve the beauty of their works not to have adopted this arrangement.

These early productions were, in form, generally large or small folios, or quartos; the lesser sizes not having come into use. The leaves had no running title, numbering of pages, or divisions into paragraphs. The character was a rude old Gothic, mixed with Secretary, intended to imitate the hand-writing of the time; the words were so close together as to make it difficult to read them; the orthography was various, and often arbitrary, disregarding method. There were frequent abbreviations, which in time became so numerous, that in order to understand them, it was necessary to have a book specially devoted to their explanation. Periods were only of two kinds—namely, the colon, and the full-point; afterwards an oblique stroke was introduced, thus, /, which answered the purpose of our comma. No capital letters were introduced to begin a sentence, or for proper names of men or places. Blanks were left for the places of titles, initial letters, and other ornaments, in order to have them supplied by the illuminators, whose ingenious art did not long survive the improvements of printing. Those ornaments were exquisitely fine, and curiously variegated with the most beautiful colours, and even with gold and silver; the margins likewise were frequently charged with a variety of figures of saints, birds, beasts, monsters, flowers, &c., which had sometimes relation to the contents of the page, but often none at all. These embellishments were very costly, but for those who could not afford a great price, there were inferior ornaments, which could be done at a much easier rate. The name of the printer, place of his residence, &c., were either entirely neglected, or put at the end of the book, not without some pious ejaculation or doxology. The date was also omitted, or involved in some circumstantial period, or else printed either at full length, or by numerical letters, or both together, (as "one thousand cccc and lxxiiii," &c.) but all at the end of the book. There was no variety of characters, no intermixture of Roman and Italic, but the pages were continued in a Gothic letter of the same size throughout. The copies were few, two or three hundred being considered a large impression, though upon encouragement received, they soon increased their numbers.

Copies of these early works are eagerly sought for by a certain class of book-collectors, and we occasionally hear of enormous prices being given for authentic copies of a rare work. The most extraordinary example of this occurred at the sale of the Duke of Roxburghe's library in 1811, when the object of competition was a copy of the first edition of *Il De Camerone di Boccaccio*, printed at Venice by Christopher Valdarfar in 1471. It was a unique copy, and eagerly coveted by many celebrated libraries; but the chief competitors were Earl Spencer and the Marquis of Blandford, and it was finally knocked down to the latter for the sum of 2,260*l*. The Marquis already possessed a copy of the same edition, wanting only a few leaves at the end. This price is of course excessive and exceptional; but other books sold for large sums, such as several hundred pounds each. The copy of the *Recuyell of the Historyes of Troye* presented by Caxton to Elizabeth Grey, Queen of Edward IV., was purchased by Mr. Ridgway for 1,000 guineas.

Such is a brief history of the invention of the art of printing, which has effected such vast changes in the political and social condition of men, and which it is probable will effect changes still greater, and more momentous. At the time when it pleased Omnipotent Wisdom to allow this invention to dawn upon mankind, the feudal system was but slackening its iron grasp on the lives and fortunes of men, and a corrupt priesthood still held unlimited sway over their thoughts and actions. The increasing importance of the towns and trading communities was rising superior to the feudal castle; the growing intelligence resulting from the freer intercourse between people and nations in the exercise of their peaceful pursuits, now began to call in question the arrogant authority of an intolerant Church. The minds of men were preparing for the Reformation, which the printing of the Holy Scriptures tended so much to accelerate. The printing-press became the grand means of communication between the teacher and the taught, and if the teacher taught falsely, his book remained open to the censures of all, while the words of oral instruction might be as fleeting as the waves of sound which conveyed them to the hearers. Thus, while the printing-press embalms the thoughts of the wise, the good and the great, for the benefit of its own age, and of succeeding ages, it is the duty of all concerned in its ministration to use their best endeavours to preserve it as a source of truth, purity, liberty, and justice. And as this mighty machine is powerful for good, it may also be made powerful for evil; so it is the duty of every writer, of every

publisher, of every printer, of every compositor, to preserve it from disseminating falsehood, blasphemy, and pollution. This is the more necessary now than at any previous time, because there are more readers; their number is daily increasing, and the time is not far distant, when not to be able to read will be regarded as a mark of degradation by every one who breathes the air of freedom, and worships God under the mild toleration of a reformed Church.

Section II.—Type-founding.

The art of printing had attained its most valuable and distinctive form when Gutenberg and his partners had succeeded in realizing the idea of cast metal types. There is sufficient evidence that such types were used by the firm before the secession of Gutenberg, and although Peter Schöffer may justly claim much of the merit of practically carrying out the idea, yet the other two partners must not be forgotten in the award of praise. Fust was a worker in metals, and must have been well acquainted with the not inconsiderable resources of his time in casting and founding. But there were many difficulties in carrying out Gutenberg's original idea of moveable metal types. The founding of type is one of the most delicate and exact specimens of casting in metallic moulds that is now practised; we may, therefore, form some idea of the great merit of this invention by endeavouring to realize the time when it did not exist. It is not possible to do this with anything like completeness, for inventors are not in the habit of exhibiting or detailing the successive steps and the innumerable failures which mark the progress of an invention. They are satisfied with the successful result, and even that they endeavour to conceal as long as possible, in order that they may reap the reward of their labours. It is, however, very probable that the first plan was to strike a letter of approved cut, answering to the modern punch, into soft clay or plaster, and to pour the metal into the mould thus formed; the shaft or body of the letter would then have to be dressed into shape by hand. This slow and imperfect method was gradually superseded by the invention of the highly ingenious metal mould now in use; but on this point we have no certain information, for the invention was kept a *mystery* for half a century. The printers' device of Badius Ascensius, of Paris and Lyons, exhibits a foundry similar to the modern. The early printers, who did not cut their own types, do not appear to have had any difficulty in procuring letter. Caxton obtained his types from Ulric Zell, father of the Cologne press; but when Caxton settled in England he began to cut type in imitation of the writing common in England at the period. Wynkyn de Worde supplied many cotemporary printers with types, of which his black letter was and is still greatly admired. In 1637, the art of type-founding was separated from that of printing by a decree of the Star-Chamber, and four founders were appointed, who enjoyed the monopoly of supplying the whole kingdom with type. This absurd and unjust restriction could not, of course, be continued for any length of time; but it seems to have had the effect of erecting the type-founder's art into a distinct trade, as it is at present.

The necessity for this distinction will be evident when we consider how great is the demand for printing, and consequently for letter, at the present day. The type-founder's art is also one of great complexity, not only on account of the large number of sizes of type in common use, but also the large variety of *sorts*, or characters, belonging to each size. There are two kinds of founts which are used respectively for *book-printing* and *job-printing*, the latter including such work as hand and posting bills, &c. Book types include eleven or twelve regular bodies, from *Great Primer*, which is the largest, to *Diamond*, which is the smallest type used for printing books. The following are specimens of book types:—

Price per 1,000.	Names of the various sized types.	Specimens of the various sized types.
	Great Primer.	The art of Printing was introduc
	English.	The art of Printing was introduc·ed into
6*d.*	Pica.	The art of Printing was introduc·ed into England
	Small Pica.	The art of Printing was introduc·ed into England by
	Long Primer.	The art of Printing was introduc·ed into England by Willi
	Bourgeois.	The art of Printing was introduc·ed into England by William Cax
	Brevier.	The art of Printing was introduc·ed into England by William Caxto
6¼*d.*	Minion.	The art of Printing was introduc·ed into England by William Caxton, i
7*d.*	Nonpareil.	The art of Printing was introduc·ed into England by William Caxton, in 1474: he
8*d.*	Pearl.	The art of Printing was introduc·ed into England by William Caxton, in 1474: he erected his pre
10*d.*	Diamond.	The art of Printing was introduc·ed into England by William Caxton, in 1474: he erected his press in a chapel at Westminster.

Great Primer is the largest type used for books; it is used in large Bibles, and is hence called *Bible text*, but is now seldom employed. It is double the body of Bourgeois, and about 51¼ m's form a foot.[1]

English is used for Church Bibles, and works in folio and quarto. There are 64 m's to a foot, and its body is equal to two Minions.

(1) The letter m being on a perfectly square shank, is taken as the standard of comparison in types, as will be further noticed in a subsequent section.

Pica forms the general standard of measurement in casting leads, quotations, cutting rule, and regulating the price of press work. It is much used for works of a standard character, such as history, art, &c. There are 71 m's to a foot, and it is equal to two Nonpareils.

Small Pica is perhaps the most extensively used letter. Novels are printed in this body. It is equal to two Rubies, and has 83 m's to a foot.

Long Primer is much used for works in 12mo., dictionaries, and other works in which much matter is required to be got into a small space. It is equal to two Pearls, and there are 89 m's to a foot.

Bourgeois much resembles Long Primer, but it has 102 m's to a foot, and is equal to two Diamonds. It is the type used in the present Cyclopædia.

Brevier, formerly used for printing *breviaries*, is much used for small works, and for notes. 112½ m's to the foot.

Minion is used for pocket editions, Prayer-books and Bibles, and also for advertisements. 128 m's to the foot. It is half the size of English.

Nonpareil, 143 m's to the foot: half Pica. It is used for the same purposes as Minion.

Pearl, 178 m's to the foot; half Long Primer.

Diamond contains 205 m's to the foot. *Ruby* is a size between pearl and diamond.

It must be remarked with respect to the above sizes that, although a skilful printer would be able to name any size at the sight of merely a single letter of the fount, and even be able to state what foundry it came from, and who cut the punch, yet, for want of a uniform standard, the same named letter will vary with different founders, and even with the same founder, so that it is seldom that two founts will stand together.

Each of the above founts of type consists of five alphabets, viz., A, ᴀ, a, *A*, *a*, together with many other characters, about 200 in all, and these must all be exactly alike, except in *device* and *width*. The greatest width is for the W and M, and the least for the i and ! .

Every one of these numerous characters requires for its formation a *punch*, a *matrix*, a *mould*, and *type metal* in the fused state. The punch is a piece of steel with a single letter at one end. It is formed by hammering down the hollows and filing up the edges of the metal in a softened state. Each letter must harmonise with all the others in the fount with regard to height, breadth of stroke whether heavy or fine. In engraving the letter at the end of the punch, the artist should aim at an elegant symmetry, and should not affect an odd or peculiar character, or the imitation of those antiquated forms which were made at a time when no better could be produced. This is one of the great weaknesses of modern designers: they select some time in the middle ages as the halcyon period of art, and copy or imitate the bad and the good, forgetting that the bad was the best that could be produced in its day, and that the artists would have produced better had they been in possession of our improved means. The qualities which the letter engraver should aim at securing are elegance and sharpness of appearance, combined with strength and durability.

The matrix is a small piece of copper, two forms of which are shown in Figs. 1726, 1727. It is about 1¼-inch long, ⅛-inch deep, and wide in proportion to the size of the type: into this the hardened punch is struck. This must be managed with care, so as to allow the faces of the types, when composed or set up, to be in a perfect plane. Hence the depth of the impression in the matrix is of great importance, and it is usual to adjust this depth by filing down the surface of the copper.

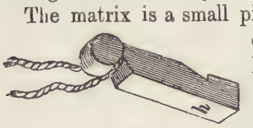


Fig. 1726


Fig. 1727.

The matrix having thus received a sunken impression from the raised letter on the punch, all that is required is to pour a quantity of fluid metal into the matrix in order to reproduce the letter as it is engraven on the punch. But in addition to this the cast letter will require a support, or *body*, *b*, Fig. 1728, an appropriate width *w*, and certain nicks or notches seen below *w*, which enable the compositor to place the letter in the proper position in his composing-stick without having to examine every letter by eye.

The measure of the type with regard to height, width, and body, is determined by the *type-mould*, which is somewhat peculiar in its construction. It is not formed like the usual forms of square moulds, Fig. 1729, for it is required in type founding that various widths shall be produced from the same mould; and it is evident that the mould, Fig. 1729, does not admit of a ready contraction, for if the piece *p* be slid upon the mould in the direction of the dotted lines, it would not alter the width of the type represented by the shaded portion. So also, if the mould were formed of two parts, as represented in Fig. 1730, and one part were slid upon another after the melted metal had been poured into the central square cavity, there would indeed be a contraction in width, but this would be attended with a distortion in form, as shown by the shaded part, out of the mould. If, however, the mould were made in two parts, as represented in Fig. 1731, it is evident, that by sliding one part upon the other, the square cavity in the

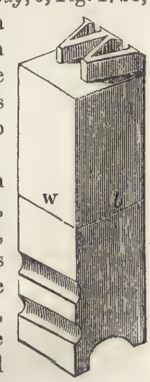


Fig. 1728.

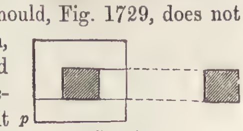


Fig. 1729.

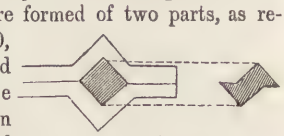


Fig. 1730.

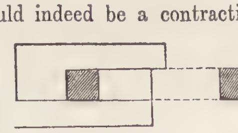


Fig. 1731.

centre, while retaining the same height, would have its width diminished to any extent required. It is upon this principle that the type mould (Fig. 1732) is constructed. The two parts (which are of steel,

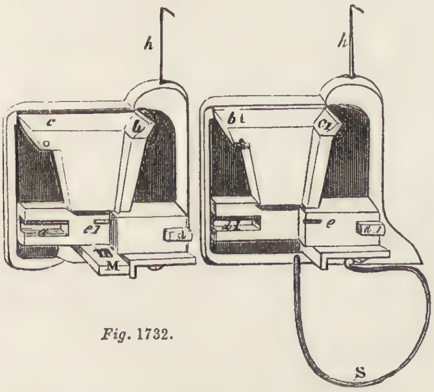


Fig. 1732.

each with a cover of wood on the outside) are so contrived, that, on being put together, a' fits into a, d into d', e' into e; c falls upon c', and the two halves form in the centre e' a space or mould in which the type is formed: the matrix M is placed at the bottom of the mould, and is retained in its place by the spring s, and the extent to which the two parts of the mould slide upon each other is determined by the width of the matrix. The metal is poured in at the orifice formed by closing the upper parts, and the newly cast letter cannot be disengaged without opening the mould: the letter is removed from the mould by bringing down one of the hooks, h, to the waste piece attached to the base of the letter.

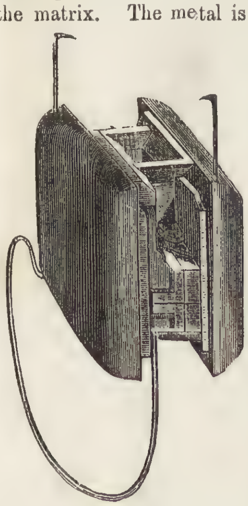


Fig. 1733.

These details being understood, a few words will suffice to explain the operation of casting. The caster stands by the side of a furnace containing the melting-pot and the fused type-metal, (the composition of which is given under ANTIMONY; see also ALLOY.) He holds the mould in his left hand, and taking up a portion of the metal, in a very small ladle, held in the right, he pours a sufficient quantity of it into the mould, and immediately jerks it up for the purpose of expelling the air from the cavity and driving the metal into the finest strokes of the matrix. Then, by means of one finger, he releases the spring, separates the mould, and hooks out the letter, which has the appearance represented in Fig. 1734. A good caster will produce 500 letters an hour of ordinary sized type. The small and the large sizes require more time: the former, on account of the increased care, and the latter, to allow the metal to set.

The types are removed from the caster's table by a boy, who, seizing the type by the edges, breaks or bends off the superfluous metal at the bottom with such rapidity, that one boy will break off from 2,000 to 5,000 in an hour. He then conveys them to a man seated at a table, who, with his finger protected by a piece of tarred leather, rubs the side of every letter on a slab of gritty stone for the purpose of removing knobs or globules. One man can dress from 1,500 to 2,000 letters per hour. The letters are next set up by a boy, in lines, in a long stick, or shallow frame, with the faces uppermost and the nicks outwards. With the assistance of other frames, a man called the *dresser* polishes the types on each edge, and turning them with the face downwards, planes the bottom, and forms the groove which brings the types to the required height, and enables them to stand steadily; the letters are carefully inspected with a lens, and the fount being *proportioned,* i. e. the proper proportion of each letter, together with the spaces, quadrats, &c., being counted out, each letter, &c. is tied up in lines of convenient length for the printer. A complete fount of pica weighs 800 lbs.

Fig. 1734.

For very large types a punch is not used. They were formerly cast in sand moulds, and hence called *sand-letters;* but they are now cast in matrices, which are made as follows:—The letters having been accurately shaped by means of a rule and compasses on a piece of copper or brass, are cut out, the back being left a little wider than the front, the sloping edge forming the shoulder of the future type. The piece of brass is riveted on a smooth surface of brass, which forms the face of the letter in the casting. Large types are also formed of wood. *Script* or *writing-type* requires the fine strokes of each letter to be carefully adjusted, and from their liability to wear and become battered, this forms an expensive variety of type.

Attempts have been made of late years to produce type by means of dies and powerful pressure. We have seen a machine for making *apyro-type*, or *type without heat,* which on being turned by hand, produced type punched out of copper of singular sharpness and beauty. In the Great Exhibition there were several machines of this kind, one of them capable of producing 4,000 types in an hour.

SECTION III.—COMPOSING, IMPOSING AND CORRECTING.

Supposing a new fount of type to be received at the printing office, the first operation is to *lay* it in the *cases*, Figs. 1735, 1736, of which there are two, the *upper* and the *lower* case. The upper case is divided into equal spaces or boxes; the left-hand division containing capital letters, dotted letters, figures, fractions, and a few other particular sorts; the right-hand division containing small capitals, accented letters, note references, &c. In the upper case, the letters and figures are arranged in their alphabetical and numerical order from left to right. In

the lower case, the divisions are unequal; those letters which are most in request having the largest divisions assigned to them. Thus the letter e has the largest box; c, d, m, n, h, u, t, i, s, o, a, r, have respectively boxes of twice the size of those containing the letters b, l, v, f, g, y, p, w, and four times the size of z, x, j, q, or the crotchets [ ], points, and full-points, double and treble letters, &c. The letter k occupies a spare box in the left-hand division of the upper case. The *logotypes* ff, fl, fi, ffi, and ffl, are necessary, because the kerned f cannot be placed close to another f, an i, or an l. The boxes of letters most in request are nearest at hand. There is a separate pair of cases for the *italic* letters.

UPPER CASE.

A	B	C	D	E	F	G	A	B	C	D	E	F	G
H	I	K	L	M	N	O	H	I	K	L	M	N	O
P	Q	R	S	T	V	W	P	Q	R	S	T	V	W
X	Y	Z	Æ	Œ	U	J	X	Y	Z	Æ	Œ	U	J
ä	ë	ï	ö	ü	ç	£	á	é	í	ó	ú	§	‡
1	2	3	4	5	6	7	â	ê	î	ô	û	‖	†
8	9	0	¼	½	¾	k	à	è	ì	ò	ù	¶	*

LOWER CASE.

—	[	æ	œ	j	’	e	thin spaces	(	?	!	;	⎧	fl
& / hair spaces	b	c		d		e	i	s		f	g	⎨ / ⎩	ff / fi
ffi / ffl	l	m		n		h	o	y	p	,	w	n quadrats	m quadrats
z / x	v	u		t		thick spaces	a	r		q / .	: / -	Quadrats	

Figs. 1735, 1736.

The proportions in which the letters are supplied and distributed in the boxes, is as follows :—

Capitals, of each, from 400 to 600.
Small capitals .... 150 to 300.

a,	8,500	f,	2,500	p,	1,700	x,	400
e,	12,000	g,	1,700	q,	500	y,	2,000
i,	8,000	h,	6,400	r,	6,200	z,	200
o,	8,000	j,	400	s,	8,000	,	4,500
u,	3,400	k,	800	t,	9,000	;	800
b,	1,600	l,	4,000	v,	1,200	:	600
c,	3,000	m,	3,000	w,	2,000	.	2,000
d,	4,400	n,	8,000				

The whole fount includes not less than 150,000 letters, figures, spaces, &c.

The compositor, standing before the case, Fig. 1737, places his *copy*, i. e. the author's manuscript,

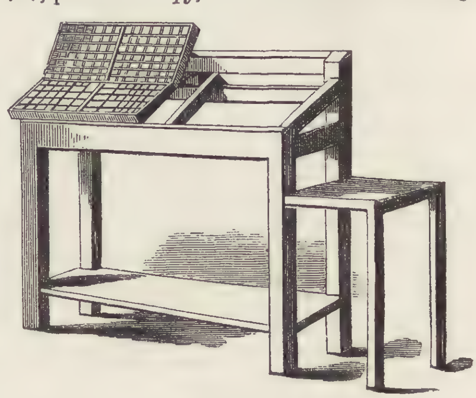


Fig. 1737.

on that part of the upper case which is but little used, and having previously received directions as to spac-

ing, &c., he takes in his left-hand a *composing-stick*, Fig. 1738, in which he fixes the exact length of the line by sliding the inner movable portion, and fasten-

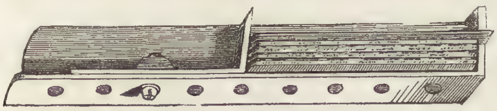


Fig. 1738.

ing it by a screw. He next selects a piece of brass rule, called the *setting* or *composing-rule*, of the exact length of the line, and with a small ear or beak projecting at one end, for lifting it out of the composing-stick, in which it is placed in order to allow the letters to slip into their places without any obstruction from the screw-holes of the stick, or the nicks in the type. The setting-rule has also another use, which will be noticed presently. The compositor being prepared with this simple apparatus, begins work thus:—looking at his copy, and carrying a line or two in his memory, he takes a capital letter from the upper case, and places it in the left angle of the composing-stick; he selects the remaining letters of the first word from the lower case, and at the end of the word inserts a *space*, which is merely the shank of a letter without any face, and not so high as a letter by one-fourth. These spaces serve to mark the divisions between words, and being below the plane surface of the type, they receive no ink, and consequently do not appear on the printed page. When the compositor arrives at the end of a line, and finds that he cannot get in a whole word, nor even a syllable of such word, he must nevertheless contrive to make the words and spaces of the line exactly fill it without being too tight or too loose, the reasons for which will be evident hereafter. If the words and spaces already composed do not quite fill the line, he takes out some of the spaces first inserted, and puts thicker ones in instead. Or if he cannot get in the last word of the line by a letter or two, he removes some of the thicker spaces, and inserts thinner ones. He must, however, so manage his spaces, that the composed matter shall not appear either too white or too dark. Correct spacing is one of the tests by which a good compositor is distinguished from an indifferent one. A good compositor will measure with his eye, as he proceeds with his work, the exact number of words, syllables, and spaces which the line requires, and adjust them accordingly; whereas another man will have to do his work over again by taking out, fitting and contriving after the line is composed.

Supposing the compositor to have arrived at the end of the first line, he takes out the setting-rule, and puts it in front of the line, which he forces back, and proceeds to the second line. In this way the lines are composed, the setting-rule being taken out at the completion of each line, and put in front of that line, so as to form the basis for a new one. If the matter is to be *leaded*, i. e. if the lines are to be further apart than the type alone will allow, a flat ribbon of metal, called a *lead*, of the exact width of the page, but only $\frac{1}{4}$th, $\frac{1}{6}$th, or $\frac{1}{8}$th as wide as the type, and not higher than the spaces, is inserted after the completion of each line, and before the setting-rule is removed. If the page is to be *thick leaded*, two or more leads are placed before each line; but if *thin leaded*, one lead will suffice. When the work is double-leaded, or has *reglet* between the lines, reglet being of the thickness of the type, the spacing between the words should be thicker than when the work is *solid*, or without leads. There are several sorts of spaces in the boxes, so that the compositor in using thick spaces can *justify*, or make his line fit properly with thinner and hair spaces. It is also the compositor's duty to correct the punctuation of the author, which is generally both deficient and incorrect. This he does quite as much by following certain rules, as by making out the sense of the passage which he is setting up.

The rapid and apparently eccentric motions of a compositor at case, generally excite the surprise of persons unacquainted with printing, who visit a printing office for the first time. A compositor may, however, make a number of rapid motions, and yet lose time over his work, because they are either ill-directed, or positively useless. A good compositor makes no false motions, his fingers aim at one particular letter, he takes it up by the face end, and if the nick be not upwards, he turns it upwards in its progress to the composing-stick; and before it is actually inserted, his eye is directed to the next letter, which he picks up and conveys to its destination with as few motions as possible.

When the composing-stick is nearly full—it may contain 6, 8, 10, or 12 lines, according to the size of the type—the composed matter is lifted out, and deposited in a long frame called a *galley*, Fig. 1739; for which purpose, the setting-rule laid on the last line allows the whole of the matter in the stick to be grasped tight between the fingers of both hands, the rule preventing it from falling to pieces. This, however, re-

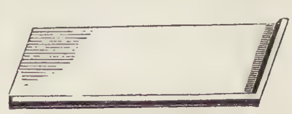


Fig. 1739.

quires skill, for if not properly grasped, the *stickful* of type, as it is called, will fall to pieces, forming what is technically known as *pie*. When a considerable quantity of matter has thus been collected in galleys, the compositor proceeds to make it up into pages, and then into sheets. Taking the proper number of lines for a page, he adds at the bottom a line of quadrats, which resemble the spaces, but are much larger, being 3, 4, 5, or 6 times as long as they are broad: he next places on the top the folio of the page, and the running head, or line which indicates the title of the work, or the subject of the chapter, or, still better, of the page,[1]

(1) The usual practice of inserting the short title of the book on every page, or alternate page, is an absurd one, since it reiterates information which the title supplies, and is not wanted elsewhere. But as custom and the symmetry of the page require a running head, it would be very desirable if the author or the corrector of

and then adds such leads as are wanted. At the bottom of the first page he places the *signature,* or letter of the alphabet, which is intended as a guide in *gathering, folding,* and *binding* the sheets. [See BOOKBINDING.] The page thus formed is tied tightly round with string, or *page-cord,* as it is called, and placed on a piece of coarse paper. Having made up as many pages as the sheet consists of,—4 for folio, 8 for quarto, 16 for octavo, &c.,—he places them upon a large slab of marble let into a frame, and called the *imposing-stone.* The pages are of course imposed on the stone in an order the reverse of that in which they appear in the printed sheet, the first page on the right-hand being at the extreme left in the type, and so on. When the pages are properly placed, the compositor takes an iron frame called a *chase,* which is divided by cross-bars into compartments, the inner angles of which are carefully squared, and places it over the pages, and adjusts between them a number of pieces of wood or metal called *furniture.* Within the chase, next to the pages, he places other pieces of iron, called *side* and *foot-sticks,* which are rather wider at one end than at the other, and between these and the chase he drives in small pieces of wood, named *quoins,* which decrease in width in the same proportion as the side-sticks. By means of a mallet and a *shooting-stick* (which is a piece of wood 1 foot long, $1\frac{1}{2}$ inch wide, and half an inch thick), he drives the quoins towards the thicker ends of the side and foot-sticks, and the quoins thus act as gradual and powerful wedges, forcing the separate pieces of type into a compact body, so that all the sides of the pages being many times *locked up,* the whole mass of many thousand letters may be lifted off the stone. This united mass is called a *form,* the one containing the first page is the *outer,* and the other the *inner* form. [See BOOKBINDING.] The two forms of an octavo sheet are shown in Fig. 1740.

The compositor is paid at a certain rate for every thousand letters composed. The letters are not actually counted, but they are estimated by assuming as the standard the letter m, on account of its being on a perfectly square shank; then supposing the page to be solid or unleaded, it is ascertained how many m's of the particular fount the page is long, including the running-head at the top and the white-line at the bottom. The width of the page is next found, or how many times the letter m would be repeated in a line of given length. But as nearly all the other letters are of much smaller width than the letter m, the number of m's in a line fails to represent the average quantity; now it has been found by experience that the average width of the letters is half their depth, or half the width of the letter m. Hence the number of m's in the length of the page multiplied by twice the number of m's in the width, and this product by the number of pages in a sheet, gives the average number

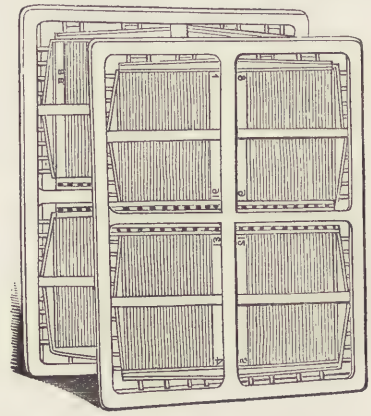


Fig. 1740.

of letters per sheet. For example, in *casting up,* as it is called, a sheet of octavo in pica, suppose it be 46 m's long and 22 m's wide: then $46 \times (22 \times 2) \times 16$ (the number of pages in an octavo sheet) $= 32{,}384$. In such case the compositor would be paid for 32,000 letters, the odd hundreds, &c. being omitted unless they exceed 500, which are paid for as 1000. If the sheet be in solid type of the ordinary size the compositor's price in London is 6*d.* per 1000. The prices for the other types are given with the specimens in Section II. If the type be leaded the price is $\frac{1}{4}$*d.* per 1000 less: if the work be composed from a printed copy, the price is $\frac{3}{4}$*d.* per 1000 less, (MS. copy, and especially the MS. copy of some authors, being difficult to read, and consequently consuming more time than printed copy.) Some kinds of work, such as tables of figures, which form a dense mass of type, are paid double. Works in a foreign language are paid $\frac{1}{2}$*d.* per 1000 more in type of the ordinary size, and $\frac{3}{4}$*d.* per 1000 more in smaller type. For Greek, with leads and without accents, $8\frac{1}{2}$*d.* per 1000 is paid; without leads or accents, $8\frac{3}{4}$*d.*; and with accents, $10\frac{1}{4}$*d.* Hebrew, Arabic, &c., are paid double. The rate per thousand paid to the compositor includes not only the composing, but the making-up into pages, imposing, correcting any errors which he may have committed; and when the impression has been worked off, and the type is returned to him, he has to *distribute* the letters into the various boxes of his cases before such type can be again used for setting up fresh matter. Holding a quantity of the composed type in his left hand, with the face towards him, the compositor takes up one or two words between the forefinger and thumb of the right-hand, and drops the letters each into its proper box with great rapidity. A good compositor will distribute 50,000 letters in a day. Distribution occupies one-fourth of the compositor's time; making-up, imposing, and correcting, another fourth; so that he has only one-half of his time for that labour which forms the sole datum for

the press made the running head an index to the page to which it refers. This is done in the present work, where of course it is easy of accomplishment by the compositor himself. In the Editor's work on "Rudimentary Mechanics," this plan has been carefully carried out, and it is also done in an amusing and elaborate manner in Mr. Thackeray's Novel of "Esmond." The chief reason why this useful and sensible plan is not generally adopted is, that the varied running head requires to be inserted in the proof-sheet after it is made up by the printer, and is consequently charged for as a *correction.* Whereas if the short title of the work be repeated on every page, the compositor inserts it in the making-up, and it is not charged for extra.

estimating his remuneration. In order to earn a fair week's wages he ought to be able, while composing, to pick up at the rate of 2000 letters per hour, which is at the rate of 24,000 letters per day of 12 hours, and 144,000 per week. In picking up each letter the hand has to traverse at least 6 inches on an average and back, and this exertion long continued in a standing posture (which is necessary for freedom of action) becomes extremely laborious. When it is also considered that the air of the printing-office is generally of the worst description, contaminated as it is by the fumes of printers' ink, grease and moisture from the steam-presses in the basement; vitiated by the respiration of several hundred human beings, and by the combustion of numerous gas-lights; considering, too, that some of the largest printing-offices are in the most crowded parts of the metropolis,—we have altogether as large a collection of noxious influences as may generally be found to concur in a factory in destroying the health of the persons who spend so large a portion of their lives within its walls. Our experience extends to a considerable number of the large London printing-offices; and we are sorry to have to state, that scarcely in any one that we are acquainted with, has any attempt been made to diminish that monster evil—bad air—by an efficient system of ventilation. If ordinary means were taken to let out the foul air and provide proper openings for the admission of the fresh, many of the objections to which we refer would be mitigated or removed; the men would improve in health and longevity; and the master would have the satisfaction of knowing that he had done his duty to those persons, who, while they serve him, are at the same time committed to his charge, and he is to a certain extent morally responsible for their welfare. We have no reason to hope that these observations will produce any useful result; but it is nevertheless our duty to make them, and to state distinctly that, next to intemperance, nothing is more destructive to health than the respiration of vitiated or contaminated air.

When the two forms of the sheet are removed from the imposing-stone they are conveyed to a hand-press, and a proof of the sheet is *pulled.* This proof is taken to the *first reader* or *corrector of the press,* who folds the sheet, examines the signatures, the folios, and the running-heads; sees that the pages have been properly imposed, that the chapters are correctly numbered, &c. He then compares the sheet with the author's copy, sees that underlined words are set up in *italics,* that the proper capitals are used, and that the work is done in a workmanlike manner. He then calls the *reading-boy,* who reads the copy aloud as rapidly as words can well be uttered, without much attention to the sense. The first reader being himself a practical compositor, his experienced eye enables him to detect every trifling error, such as would pass quite unnoticed by a person not in the trade; as, for example, whether a letter from a wrong fount had got into the fount used by the compositor; such a mistake is corrected in the proof by drawing the pen through the wrong letter, and writing *w.f.* for "wrong fount" opposite to it in the margin. Other mistakes are also pointed out by appropriate marks; and having gone through the sheet, he writes upon the author's copy, at the exact word, the commencement, signature, and folio, of the succeeding sheet, together with the figure for the next wood-engraving, if the work be illustrated by numbered wood-cuts. He then returns the sheet by the reading-boy to the compositors, who first examine the corrections, and gather up from their cases the words, letters, and corrections marked in the margin, and proceed to the imposing-stones, to which the forms are now returned, and *unlocking* them, they lift up with a blunt bodkin each line requiring correction, draw out the wrong letter, or word, and insert the right one, at the same time adjusting the spaces so as to allow for the increased or diminished fulness of the line. Should a word or several words have been carelessly omitted, or a word be inserted twice over, it may be necessary to *overrun* a large number of lines to the end of the paragraph, to make room for the insertion or to adjust the spacing. Should a sentence have been omitted, its proper insertion may require the overrunning of *pages* instead of lines. All this consumes a good deal of time, and indeed the overrunning is generally reckoned as equal to half the composing; that is, it takes half the time to overrun that is occupied in setting up the type in the first instance. The errors being corrected, (and sometimes new errors introduced in the process, the eradication of which requires much subsequent care,) another proof is pulled, which, with the original proof, is transferred to the first reader, who compares one with the other to see that his marks have been properly attended to: if not, he returns the proof to the compositors. But if he is satisfied, the clean proof is sent to the *second reader,* who subjects it to an intellectual as well as technical revision; it is read once more against the copy, further corrections are made, and defects in the author's style and meaning are queried. There are few literary men who would not admit the value of the services thus rendered by the second reader; and the Editor takes this opportunity of expressing his grateful thanks to those gentlemen who for many years past have read his proofs, and assisted him in making his meaning clear. The technical corrections in the second proof being made, a clean proof is pulled for the author; queries are inserted in ink, and this proof, together with the copy, is sent to the author.

Notwithstanding the care that has been bestowed upon the proof, the author sometimes finds his writing to have been misread and consequently his meaning strangely misinterpreted. Sometimes, however, the blunders in the proof escape even the author's parental eye, and regarding the proof of his work with the fond partiality of a parent, he has a keen appreciation of all the beauties, but is positively blind to the faults and defects of his work. Caleb Whiteford has published an amusing collection of "Mistakes of the Press." D'Israeli, also, in his "Curiosities of Literature," has given a list of some of the more celebrated errors which have passed through large editions of well-known works, and have even caused such works to be

sought out by book collectors, and valued for their very blunders. Thus the "Vinegar Bible," as it is called, is a curiosity in its way on account of the "Parable of the vineyard" being made the "Parable of the vinegar." There are many other such books. Some of the most curious blunders, however, occur in authors' proofs. For example, in the editor's "Student's Manual of Natural Philosophy," published in 1838, in the chapter on "The Telescope," at p. 491, the following passage occurs as it was written —"the light received from any luminous body is not to be considered as a whole, and coming from the entire surface, but as a part, and made up of a great number of bundles of *rays*—one bundle proceeding from every distinct point of the luminous body." When the author received his proof the word marked in italics was printed *rags*. In the present Cyclopædia some remarkable blunders have also occurred in the author's proofs. For example, in the article Iron the following passage, as written by the editor, ran thus:—"In the moulds left by the decomposition of shells and *madrepores*, the shapes of which are assumed by the mineral," &c., the word in italics was printed *mud-refuses*. In the article Lead it is stated that "protoxide of lead melts at a red heat, and in this state attacks silica *with ease*, penetrating an earthen crucible in a few minutes." In the proof the words *with ease* were printed *with rage*. In a reference from Oblique-Arch to Skew-Bridge the proof had "See Kew-Bridge." Errors of this kind show how necessary it is for the author or editor to be careful and watchful in reading his proofs, and comparing the revises with the corrected proofs. Some of the early printers justly prided themselves on the correctness of the editions which they issued. Thus Aldus (the inventor of the Italic and the improver of the Roman letter, who established a printing-office at Venice in 1496) considered it his chief duty to correct every sheet; and so busy was he with this employment and the multifarious business of his office, that he declared in one of his letters that he could scarcely take food or strengthen his stomach owing to the multiplicity and pressure of business; "meanwhile, with both hands occupied, and surrounded by pressmen clamorous for work, there is scarcely time even to blow one's nose." His son and grandson sustained his reputation, and the Aldine editions are much prized for their accuracy. One remarkable feature in these editions is the absence of points and stops in the title-page, a peculiarity which is imitated in the so-called Aldine editions of the poets published a few years ago.

When the author has corrected his proof, and returned it to the printer, the author's corrections are made, and charged for extra; and as the extent of these corrections depends upon the author, and vary in every page, the charge for the same is subject to considerable variations. This is one of the most unsatisfactory parts of printing, and often brings the author, the printer, and publisher into disagreeable collision. If the author's corrections are numerous, a second author's proof, called a *revise*, is sent to him; and if the author be a gentleman of uncertain temper or careless mind, or should happen to be unusually critical while reading his proof or revise, he may introduce such extensive insertions and corrections, as to make the cost for correction equal or even exceed that for composing. When, however, the author is satisfied with the first, second, third, &c. revise, he marks it "For Press," with the date, and returns it to the printer. The "Press Proof," as it is called, is once more read with a view to weed out any remaining technical errors, to correct the spacing, to take out defective letters, &c.; and at length, all corrections being made, the printer marks on the proof the number of copies to be printed, and sends it to the press-room.

There are various other details respecting the management of proofs, which are of too technical a character to be of interest to the general reader. These are better learned from experience than from books, and are moreover exceptions to the general practice such as we have described it.

Section IV.—The Printing-Press.

The earliest form of printing-press was nothing more than an ordinary screw-press, with a contrivance for running the inked form of types under the screw. With such a press, printing was a slow and laborious operation: the screw was brought down upon the form with a dead pull, to the great danger of injuring the faces of the letters. This press was greatly improved by Willem Jansen Blaew, a mathematical instrument-maker of Amsterdam. He printed many books and maps constructed from the observations of Tycho Brahe, who for many years employed him as an assistant, and for making his instruments. Blaew's press continued in general use up to the beginning of the present century. It is represented

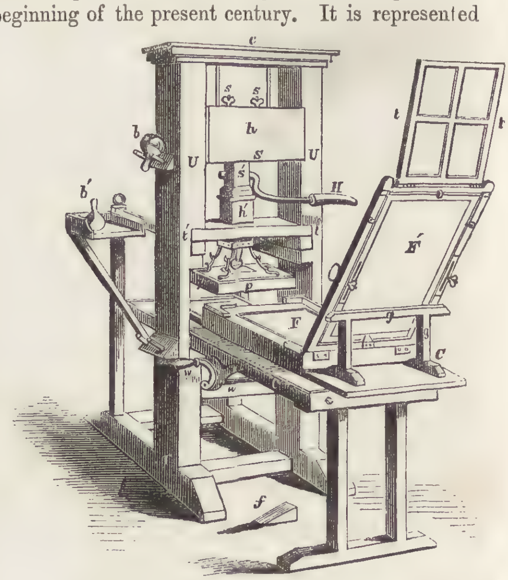


Fig. 1741. COMMON PRINTING-PRESS.

in Fig. 1741, in which U U are two cheeks or uprights, bound together by 4 horizontal bars, the first of which *c* is called the *cap;* the second, or the *head*

h, is fitted by tenons at the ends into mortices between the cheeks. The head *h* is suspended from the cap *c* by 2 screw-bolts *s s*, and in the centre of it is fixed by 2 short bolts a brass nut containing a hollow screw or worm for receiving the upper end of the great vertical spindle or screw s, by which the pressure is produced. The third bar *t'*, called the *shelf* or *till*, is intended to guide and keep steady a part called the *hose h'*, which contains the spindle and screw. The next cross-bar *w*, called the *winter*, is for supporting the carriage. The spindle and screw *s'* is a strong vertical bar of iron terminated at the lower end with steel: its upper end is formed into a small screw, which works in the small brass nut of the head; and in the eye of the spindle, just below the upper extremity, is fixed the handle H, by which the press is worked. Under the spindle is the *platten p*, which imparts the pressure to the paper. It is suspended from the point of the spindle by the *hose h'*, a square frame or block of wood which passes through the shelves. The lower end of the spindle passes through the hose, and rests by its point in a plug fixed in a brass cup supplied with oil, which is again fixed to an iron plate let into the top of the platten. When the pressman pulls the handle H, he turns the spindle, the round of which moves in its screw box, and by its descent brings down the platten, which thus presses on the paper lying on the form of type. The platten is suspended from the spindle, and rises up again with it by means of a garter or fillet of iron screwed to the hose, and entering into a groove round the upper end of the spindle. The platten is hung truly level by 4 threads passing from its 4 corners to the 4 corners of the lower part of the hose. The form of type F, is conveyed under the platten by means of a carriage C C, which is supported on a horizontal wooden frame, the fore part being sustained by a *forestay*, while the back part rests on the winter. Below the plank of the carriage are short pieces of iron and steel, *cramp-irons*, which slide upon two long iron bars or ribs fixed on the upper part of the horizontal wooden frame. In order to run the carriage in and out upon the wooden frame, there is placed below the carriage the *split* or small spindle with a double wheel on the middle of it, round which are fastened leather belts, the opposite ends of the belt being nailed to each end of the plank of the carriage. On one of the ends of the split is fixed the winch or handle *w'*, by turning which the carriage can be run in and out below the platten. The carriage is a strong wooden plank, on which is fixed a square wooden frame forming the *cell*, in which is placed a polished stone for sustaining the form of types. To this cell are fixed stay-belts of leather, one end attached to the cell, and the other to the cheeks of the press, so as to prevent the carriage from running out too far when drawn from under the platten. On the outer end of the plank is fixed the *gallows, g*, for supporting the tympans when they are turned up to receive a new sheet of paper after each impression. These *tympans* F' are light square frames, covered with parchment. They are formed of 3 slips of thin wood, with a *headband* or top slip of thin iron. The two tympans are so constructed, that the one represented as the upper one in the cut, shall lie within the exterior one, to which it is fitted by iron hinges to the cell. Between the two tympans are placed 2 or 3 folds of blanket, for the purpose equalizing the pressure of the platten upon the surface of the types. A square frame of thin iron, called the *frisket, t t*, is attached by hinges to the headband of the exterior tympan, and is made to fall down upon the tympan, so as to enclose the sheet of paper which is to be printed between them. The tympan and frisket being thus folded down, lie flat on the form of types, and the carriage containing them is run beneath the platten, so that when the handle H is pulled, the platten presses upon one-half of the form of types: the carriage is then run further in with the other half of the form, and in this way, by means of two separate pulls, the impression of the types is made upon the paper. By turning the winch *w'*, the carriage is withdrawn from beneath the platten, and the tympan, on being lifted up round its hinges, rests obliquely against the gallows. The frisket is then lifted up on its hinges, and supported by a slip of wood descending from the ceiling, and the printed sheet is taken out, and a clean one put in. Every time the carriage is run out, the type is inked by means of two bulky *inking-balls*, consisting of two circular pieces of pelt, leather, or canvass covered with composition, stuffed with wool, and nailed to wooden stocks. One of these balls *b* is represented in the *ball-rack*, and the other *b'* on the *ball-block*, which contains the ink heaped up in the angle, but brought gradually down to a thin layer in front of the block.

About the commencement of the present century several defects in Blaew's press were remedied, as in the *Apollo press*, invented in France; *Prossen's press*, *Roworth's press*, but especially in the *Stanhope press*, which we now proceed to describe. In Fig. 1747, B B, the body of the press, is a cast-iron frame in one piece, firmly screwed down to a wooden cross W'. Two horizontal rails R are screwed at *p p*, Fig. 1748, to two projecting pieces cast in one piece with the body for sustaining the carriage when the pull is made. The ribs of the carriage slide in grooves in the upper surface of these rails, and are moved by the handle *w* with a split and leather, as in the common press. A brass nut or hollow screw is fixed in the upper part *s* of the body of the press, in which the upper end of the spindle works. The mode of giving the descending motion to the screw is the chief improvement in this press. This is shown separately in Fig. 1742; while in Figs. 1743, 1744, are represented the screw with a section of the internal screw into which it fits. This screw is attached above *s*, Fig. 1747, to the rim L L, while the toe C of the screw fits into the cup C, Fig. 1745, and the piece containing the cup is screwed by the holes *hh* to the platten P, Fig. 1746. The handle H, for working the press, is firmly fixed into the lower end of the vertical bar *b*, the lower point of which

moves in a hole in the main frame, while the upper end passes through a collar in a projecting piece H: being passed through this collar the end of the bar joins a short lever L, which is again connected by the link *l* with another short lever L′ fixed on the upper end of the screw. The pressman, in pulling the handle H, turns round the spindle S, and by its connexion with the rod C, &c., the

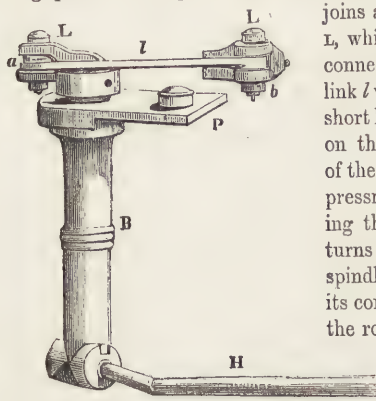


Fig. 1742.

great lever turns with it, and causes the platten to descend and produce the requisite pressure. The power of the lever H is transmitted to the screw in such a way as to produce certain required effects at different parts of the pull. At the beginning of the pull, when motion only is wanted, the handle H lies in a direction parallel to the frame across the press; and the short lever L′, which is nearly perpendicular to it, is likewise perpendicular to the connecting rod *l*: but the lever L of the

Fig. 1743.

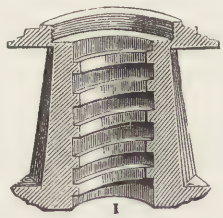


Fig. 1744.

screw makes a considerable angle with *l*, and it then acts by a spindle radius to turn the screw: when, therefore, the lever H begins to pull, the lever L′ acts with its full power upon another shorter length of lever on L, so that the screw will be turned more rapidly than if the link *l* were attached to it: the pull being continued, the position of the lever changes, the length of L always increasing from its coming nearer the perpendicular to *l* and the acting length

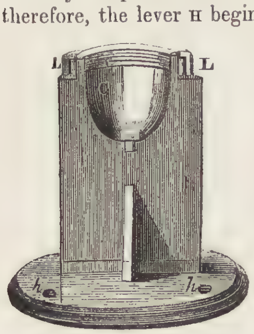


Fig. 1745.

of L′ diminishing, since by the obliquity of the lever the link approaches the centre. The handle H is now brought into a more favourable position for the pull, as the pressman finally pulls in a direction nearly at right angles to its length; by which means the platten is at first brought quickly down upon the paper where motion only is required; but as the levers are gradually coming into the most favourable position

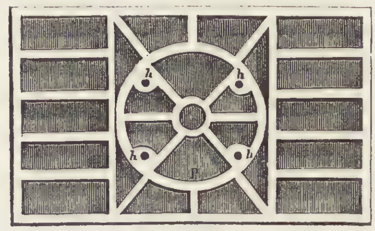


Fig. 1746.

for exerting the greatest force, this maximum pressure is produced just when it is wanted, that is, when the platten touches the paper to be printed. The range of the handle is limited by a stop, which is movable to a small extent in order to vary the pressure for different kinds of work. The insertion of the lever, by which the power is applied, into the arbor, and not into the spindle, leads to several advantages: 1. The length of the lever is equal to the whole width of the press instead of half, and is also in a better position for applying the man's strength. 2. There is the additional lever of the arbor head; 3. the additional lever of the spindle head; and lastly, the screw itself may be so enlarged in diameter as greatly to increase the power. The platten, which is screwed to the under surface of the piston, is of considerable weight, and the man would have to waste much strength in raising it from the form after the impression was made, were it not for a balance-weight W suspended upon a lever and hook at the back of the press, which counterbalances the weight of the platten, raises it from the form, and brings the bar-handle H back again ready for another pull. The form of types, T, instead of resting on a stone, as in the old press, lies upon a cast-iron block, with a perfectly flat horizontal surface, and the size of the press is such that a whole sheet can be printed at one pull. A variation in power is also obtained by a screw adjustment at the end of the link *l*, by which it can be shortened. This is done by fixing the centre pin, which unites it to the lever L, in a bearing place, and slides in a groove formed on the side regulated by the screw. In this way the descent of the platten may be increased or diminished, and its surface is turned so as to be perfectly plane. Various other improvements in this press have been patented. In one case the screw is got rid of by a spiral or curved inclined plane fixed on the head of the press. On the upper end of the spindle a cross arm is placed, which acts against a fixed inclined plane, and thus acts the part of the screw: the acting faces are made of hardened steel. In Mr. Keir's arrangement the slider *s* is formed by boring out a cylindrical hole down the centre of the press, and fitting accurately into the cylinder, to the lower end of which is fastened the platten: a flat side is made to the cylinder, which is

prevented from turning round by a bar of iron screwed across the two cheeks and bearing against the flat side of the cylinder. The lever apparatus has also been improved. In the lower end of the spindle a screw is cut and fitted into a nut; the spindle is made to rise and fall through a space equal to the descent

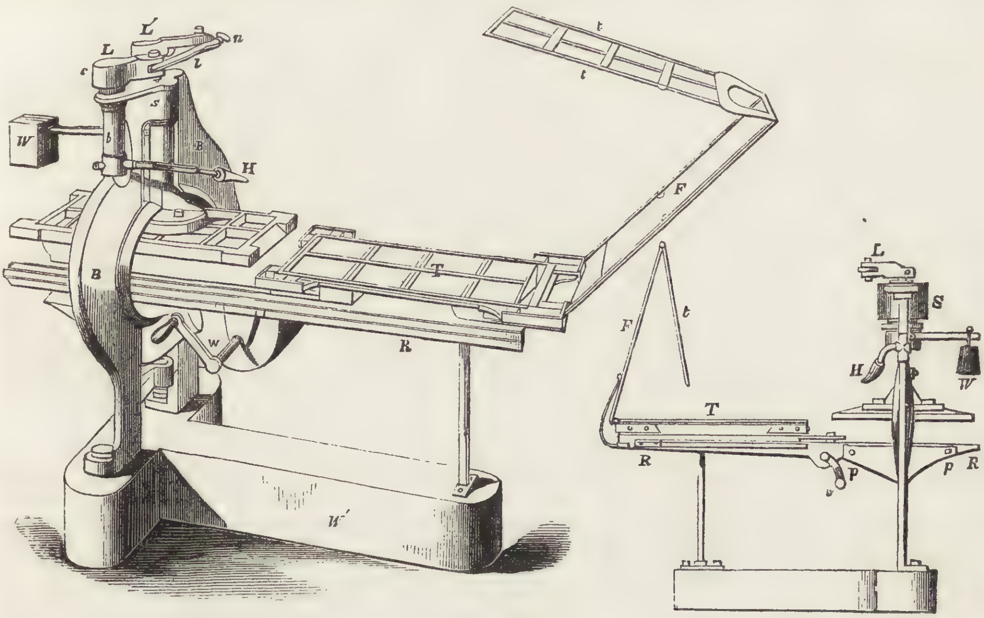


Fig. 1747. THE STANHOPE PRESS. *Fig.* 1748.

of the great screw in the same time, and the connecting rod *l*, Fig. 1747, is thus made to pull in a horizontal plane, while in the old construction one end remains level when the other descends, which occasions an unequal wearing of the joints. In the simple and efficient arrangement shown in Fig. 1749,

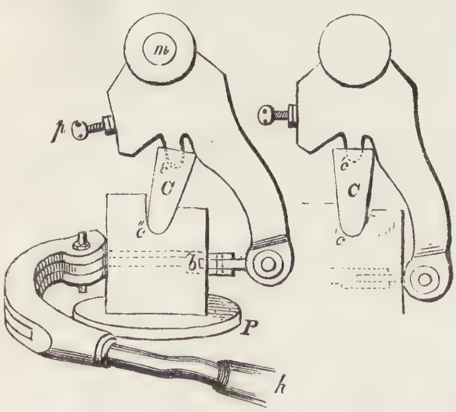


Fig. 1749.

the screw is also got rid of by means of a cam or wedge C, which fits into a cup c'', and is hollowed out above for the reception of the projection c' attached to a piece which is connected by an arm and a coupling-bar *b*, with the handle *h*. This piece is suspended by the main bolt *m* from the fixed bearings of the frame. In the position shown in the left-hand figure the platten *p* is raised, but the pressman, by pulling the handle towards him, brings the swinging piece and the wedge into the vertical, the effect of which is to send down the platten with great but regulated force, and with a very moderate expenditure of power on the part of the pressman. The range of the press may be adjusted by means of the power-screw *p*.

The press, such as we have described it, is worked by two men, one of whom inks the type and attends to the impression; the other works the press. Supposing the two forms to be correct, the inner form is first laid on the table, and secured in the centre by means of quoins. A sheet of stout paper is pasted on the frisket frame, and also secured upon the tympan. The form being inked an impression is taken on the frisket, after which the whole of the printed part is cut away, the portion which is left being intended to protect the paper from being soiled. A sheet of paper is next folded according to the crosses of the chase, and being placed on the form it is carefully opened so as to lie evenly on the form with the same margin as it is to have in the working. The tympan being wetted is closed down on the form and an impression taken, when the paper adheres to the tympan, and forms a guide for laying on the subsequent sheets with are to be printed. The points are next selected; these are pointed wires fixed in the tympan; they perforate the sheet and thus serve as guide marks to the pressman. The tympan frame is screwed on so that the points may fall into the cross of the chase. The paper is now brought from the wetting room, where it has been damped by passing it $\frac{1}{4}$ or $\frac{1}{5}$th of a ream at a time, through water, and allowing it to soak 2 or 3 days until it is evenly damped throughout. A

ream of the paper is now laid on the *horse*, which is an inclined plane, placed on the left end of a long deal table, called the *bank*, and as the paper is worked, it is brought from the tympan to the bank The bank and horse are placed at the right front of the press. The paper being supplied, the man takes a sheet and lays it carefully over the tympan sheet, closes the frisket over it, shuts down the tympan and frisket upon the form, previously inked, runs the table under the platten, pulls the handle of the lever with his full weight until it is brought down by the stop; the platten thus descends and produces the impression. Then gradually releasing his hand, the balance weight raises the platten, the bar returns to its first position, the table is run out, the tympan and frisket raised, and the frisket thrown up. The sheet is now taken off the points and examined to see whether the impression be good. The first impression is generally very defective; the parchment lining of the tympan may be thicker in some parts than in others, the blanket may be worn, or the types not quite equal in height. The men therefore proceed to *overlay;* that is, they paste on the tympan pieces of paper of the exact size of the defects, thin or thick, as may be required. If any part of the impression be too strong a portion of the tympan sheet is rubbed or cut away. Another impression is then taken, and if the men are satisfied with it, it is submitted to the overseer, who gives orders to proceed. One of the two pressmen, as already stated, inks the type and examines the impression from time to time, to see that it is of the proper colour, and that no imperfections appear in the work. When the required number of impressions of the inner form is worked off, the form is removed, washed with lye, sent to the composing room, where it is again washed, rinsed and distributed. The pressmen then lay on the outer form with as much care as the inner, and having obtained a satisfactory impression they proceed to *perfect*, that is, to complete the sheets by printing on the white sides. In this operation the points insure what is called *perfect register*, whereby the pages and lines fall exactly on the back of each other, as may be seen by holding up to the light a page of any well-printed book. Hence in perfecting a sheet by printing on the other side, the points are made to pass through the same holes. When the impression of the outer form is brought up, a thin sheet of white paper, called the *set-off sheet*, is placed over the tympan sheet, and on the points; the object of this sheet, which is frequently changed, being to keep the impression clean; for as the damp print of the side already printed impresses itself on the set-off sheet, and this again on the next sheet that is put on to be perfected, it is evidently of importance to change this sheet often.

The pressmen are paid by the *token* of 250 impressions. Supposing the number required of the work to be printed be 500, and the price for working the sheet be $4\frac{1}{2}d.$ per token, each man receives $9d.$ per sheet for 500 impressions of each form. The price, however, varies with the size of the type and of the form, with the quality of the paper and of the ink, with the number of impressions and the amount of care required. *Common* work pays $4\frac{1}{2}d.$ per token, *good* work $6d.$, *superior* $7d.$, *very best* $8d.$, $9d.$, and $12d.$ per token. Two good pressmen will complete 1 token or 250 per hour, but this varies greatly with the kind of work. For very fine work and with wood engravings the men may be limited to 50 impressions per hour, in which case they are paid by the week. The woodcuts are imposed in the chase and locked up on the table of the press. They are worked in the same manner as type, but require more care. In fine printing with woodcuts the tympan is of silk, cambric or fine broad cloth.

The ink is distributed by means of balls or rollers. The man with a ball in each hand dabs them upon a thin layer of ink in the fore part of the inking-block, and then against each other, so as to distribute the ink regularly over them. The moment the tympans are lifted up, he begins to beat the type at the right-hand near corner, and goes up that side of the form, and returns, and leaves off at the left-hand near corner, taking care to make the form feel the force of the balls by beating hard and close. In the operation of beating, the balls should be constantly turning round in the hands, as it keeps them in their proper shape, and thereby renders them more safe and pleasant to work with.[1] A corner not touched by the ball, prints pale in the next pull, and is technically called a *friar;* a spot containing too much ink, and consequently printing too black, is called a *monk*.

The roller, Fig. 1750, is a wooden cylinder with a

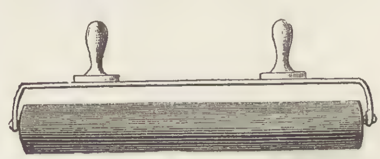


Fig. 1750.

thick coating of composition of glue and treacle: through the middle of the cylinder passes an iron rod attached to a curved bar passing over the roller and furnished with two handles. The roller revolves freely on the rod. The inking table stands to the left of the press. It is of mahogany or of iron, about 4 feet high and 3 feet 4 inches wide. At the back is a slightly elevated stage with a recess at each end, in one of which is the ink, and in the other the muller by which the ink is spread out in a thin layer in front of the stage. Some tables are furnished with a distributing roller which runs the whole length of the table, and on turning this roller it presents a line of ink to the inking roller. See Fig. 1751, in which the distributing-roller and the trough are also shown detached. The trough of ink is pressed up to the distributing-roller by means of balance-weights. The man takes up a portion of ink, and distributes it carefully on the table until the whole face of the roller

(1) Stower's Printer's Grammar, 1808. This work, which is dedicated to Earl Stanhope, contains a minute description of the Stanhope press.

is evenly covered: he then rolls the form with an equal, light and steady motion, varying his force with the size of the type and other circumstances.

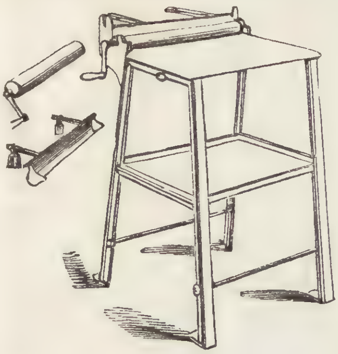


Fig. 1751.

The ink used by the early printers was black enriched with a dark blue or purple tint. It was very durable, and still offers a reproachful contrast to the brown and faded inks of more modern times. Not that the art of making good ink is lost, but that the great demand for cheap ink leads to the employment of inferior and badly-prepared materials. It will be seen by referring to our article INK, that printer's ink differs essentially from writing-ink, the former being an oily, and the latter a gummy compound. The black colour is due to lamp-black, the finest quality of which should be used, and the oil, nut or linseed, should be boiled, and burned into a varnish. The ingredients should be well mixed, and ground until quite impalpable, or the ink will clog the types and the inking apparatus, and tear the face of the paper. It should not be liable to dry when left in masses, but should dry quickly in thin layers. Turpentine is added to promote the drying. The drying of the printed sheets must not, however, be hurried, otherwise a skin will form on the surface of the letters, and prevent the under part from drying; and the consequence is, that when the sheets are pressed, rolled, or beaten for binding, the filmy skin breaks, and the ink spreads, and sets off on the opposite pages.

Ink-making constitutes a distinct branch of manufacture, and although no printers manufacture it, yet some of them add ingredients to it, which are supposed to improve its quality. Printer's ink is an expensive article: the commonest book-ink costs from 1*s.* to 1*s.* 6*d.* per lb.; but the usual quality is 2*s.* 6*d.*, 3*s.*, and 4*s.*, and for superior work 5*s.* and 6*s.*; for fine wood engravings, we have heard of 10*s.* per lb. being paid for it, but this is unnecessarily high.

Among the various recipes given for the manufacture of printer's ink, we select the following:—Fine old linseed oil boiled to a thick varnish, and cooled in small quantities, 3 gallons. A small quantity of black or amber rosin may be dissolved in it, and the mixture is to stand for some moments to deposit impurities: then mix with the finest lamp-black, and grind carefully for use. Indigo or Prussian blue may be added to improve the colour; but either of these pigments will be found to clog the ink. Turpentine is added to improve the drying quality.

Some makers are of opinion that no ink can be depended on of which oil is the basis. Balsam copaiva has been substituted. Of this, take 9 oz., of the best lamp-black 3 oz., Prussian blue $1\frac{1}{2}$ oz., Indian red $\frac{3}{4}$ oz., turpentine, soap, dried, 3 oz. This is said to produce a fine colour, but not to work clear.

When the sheets are worked off, they are hung up in the warehouse to dry by means of a wooden peel, Fig. 1752. After a day or two, they are taken down, and laid in heaps, or arranged for gathering, each signature by itself, as explained under BOOKBINDING. For the finer description of works, the sheets are *hot* or *cold-pressed*.

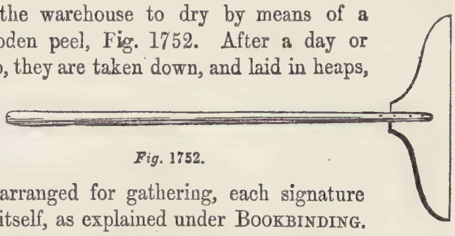


Fig. 1752.

SECTION V.—THE PRINTING MACHINE.

The printing press described in the last section was for a long period capable of supplying the demand for books and newspapers; but the important political events which occurred at the close of the last century created a demand for newspapers which the ordinary press could not supply. About the same period the general diffusion of education produced a greatly increased demand for books; while the improvements in roads and conveyances facilitated the means of distribution both of newspapers and books. The ordinary produce of the printing press was 250 single impressions, or 125 perfected sheets, per hour. It is true that a larger number was produced in newspaper offices, either by excessive labour or by means of duplicate presses and forms of type, but the production of copies was quite inadequate to the demand. About the year 1790 Mr. William Nicholson, a gentleman connected with periodical literature, took out a patent for a *printing machine* in which the type was fixed upon a cylinder which revolved in gear with another cylinder covered with soft leather; an inking apparatus being applied to the type, the paper was printed by being passed between the two cylinders. This plan does not appear to have been put into practice. The next inventor was Mr. König, a German, to whom belongs the merit of the invention of the first steam printing machine. His plan differed from Nicholson's; the type was laid upon a flat surface, and the impression given by passing it under a cylinder of large size containing the paper to be printed. This is the leading idea in the subsequent machines. König in his first machine printed on one side only, but he afterwards contrived one for printing on both sides before it left the machine. König attempted first to get his machine into use on the Continent, but not meeting with any encouragement he proceeded to London about 1804, and submitted his scheme to several printers. After many disappointments and much of the heart-sickness of hope deferred, which the needy inventors of novelties are so well acquainted with, he at length made an arrangement with Mr. Bensley, sen. Their first exertions were directed to the acceleration of the speed of the

common press, and to the dispensing with the attendance of the man who inks the types; but in accomplishing this they found "that they were only employing a horse to do what had before been done by a man."[1] The attempt to improve the common press was therefore abandoned, and the method of printing by cylinders was tried. A small cylinder machine having been constructed, it was exhibited to Mr. Walter of the *Times* newspaper, and on König's stating what further improvements were contemplated, an agreement was entered into, for erecting two machines for printing that journal. The machines were in due course erected, and on Tuesday the 29th of November, 1814, the *Times* announces the fact in its leading article in the following terms:—"Our journal of this day presents to the public the practical result of the greatest improvement connected with printing, since the discovery of the art itself. The reader of this paragraph now holds in his hand one of many thousand impressions of *The Times* newspaper, which were taken off last night by a mechanical apparatus. A system of machinery almost organic has been devised and arranged, which, while it relieves the human frame of its most laborious efforts in printing, far exceeds all human powers in rapidity and despatch. That the magnitude of the invention may be justly appreciated by its effects, we shall inform the public that after the letters are placed by the compositors, and enclosed in what is called the form, little more remains for man to do, than to attend upon and watch this unconscious agent in its operations. The machine is then merely supplied with paper: itself places the form, inks it, adjusts the paper to the form newly inked, stamps the sheet, and gives it forth to the hands of the attendant, at the same time withdrawing the form for a fresh coat of ink, which itself again distributes, to meet the ensuing sheet now advancing for impression, and the whole of these complicated acts is performed with such a velocity and simultaneousness of movement, that no less than eleven hundred sheets are impressed in one hour. That the completion of an invention of this kind, not the effect of chance, but the result of mechanical combinations methodically arranged in the mind of the artist, should be attended with many obstructions and much delay, may be readily admitted. Our share in this event has, indeed, only been the application of the discovery, under an agreement with the Patentees, to our own particular business; yet few can conceive,—even with this limited interest,—the various disappointments and deep anxiety to which we have for a long course of time been subjected. Of the person who made this discovery we have little to add. Sir Christopher Wren's noblest monument is to be found in the building which he erected; so is the best tribute of praise which we are capable of offering to the inventor of the Printing Machine comprised in the preceding description, which we have feebly sketched, of the powers and utility of his invention. It must suffice to say further, that he is a Saxon by birth; that his name is König, and that the invention has been executed under the direction of his friend and countryman Bauer."

Ten years later the *Times* again took up the subject of this admirable invention, reasserting Mr. König's claims, which had been disputed in the interval, and stating that their journal had been constantly printed by the same method, to the great advantage of the public from earlier publication and better press-work. Mr. König, it appears, had returned to his native country without having benefited to the full extent of his merits by his wonderful invention and exertions in England; but before he left this country he accomplished the last great improvement—namely, the printing the sheet on both sides. "In consequence of successive improvements, suggested and planned by Mr. König, the inventor," says the *Times* (Dec. 3. 1824,) "our machines now print 2,000 with more ease than 1,100 in their original state." The notice closes with a tribute to the strict honour and pure integrity of the inventor, and the respect and esteem in which he was held.

We put forward the claims of Mr. König on the best of all authorities, that of the *Times*, which encouraged and profited by his labours; and we do this because, in all the accounts which we have read, König's machine is either not noticed or is referred to contemptuously. This machine doubtless had its defects,—the inking apparatus, for example, contained 40 wheels, and it sometimes took up 2 hours to get the machine into working order,—but it had also great merits, not the least of which was that it served as a model for subsequent inventors; and in saying this we do not intend in the slightest degree to detract from the merits of our respected friend, the late Professor Cowper, nor of Mr. Applegath. Those gentlemen, in 1818, patented a machine in which 2 drums were introduced between the printing cylinders, and the sheet was conveyed over and under these drums in its progress from one printing cylinder to the other, the effect of which was to ensure accuracy in register. In this new machine was also introduced the plan of distributing the ink upon the tables instead of the rollers.

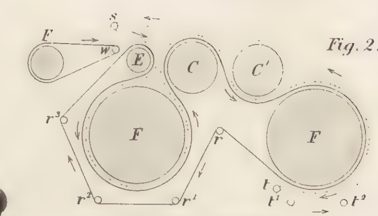
The printing of newspapers differs from that of books in this respect, that in the former case, only one side at a time is printed; but in the latter, both sides. It is easy to contrive a machine for printing first one side of a sheet, and then, substituting the inner for the outer form, to perfect the sheet by passing it through the machine a second time: but this method would not produce register; the inner form would not necessarily coincide with the outer in the perfected

(1) In the Great Exhibition were several printing presses, in which the types were inked by self-acting rollers. Such presses would indeed require the strength of a horse to work them. We have no doubt that much thought, anxiety and money were expended in these inventions; but it was a pity that the inventors had not been aware of König's failure and the cause. A well appointed Museum of Mechanical Arts, on the plan of the Conservatoire des Arts et Métiers at Paris, with models or specimens of machines, a well digested Index of Inventions, and with competent persons to answer inquiries, would form an institution worthy of the British nation, and be of essential service to inventors and the progress of invention

Fig. 3.

Arrangement of Inking apparatus.

Fig. 2.



Arrangement of Tapes.

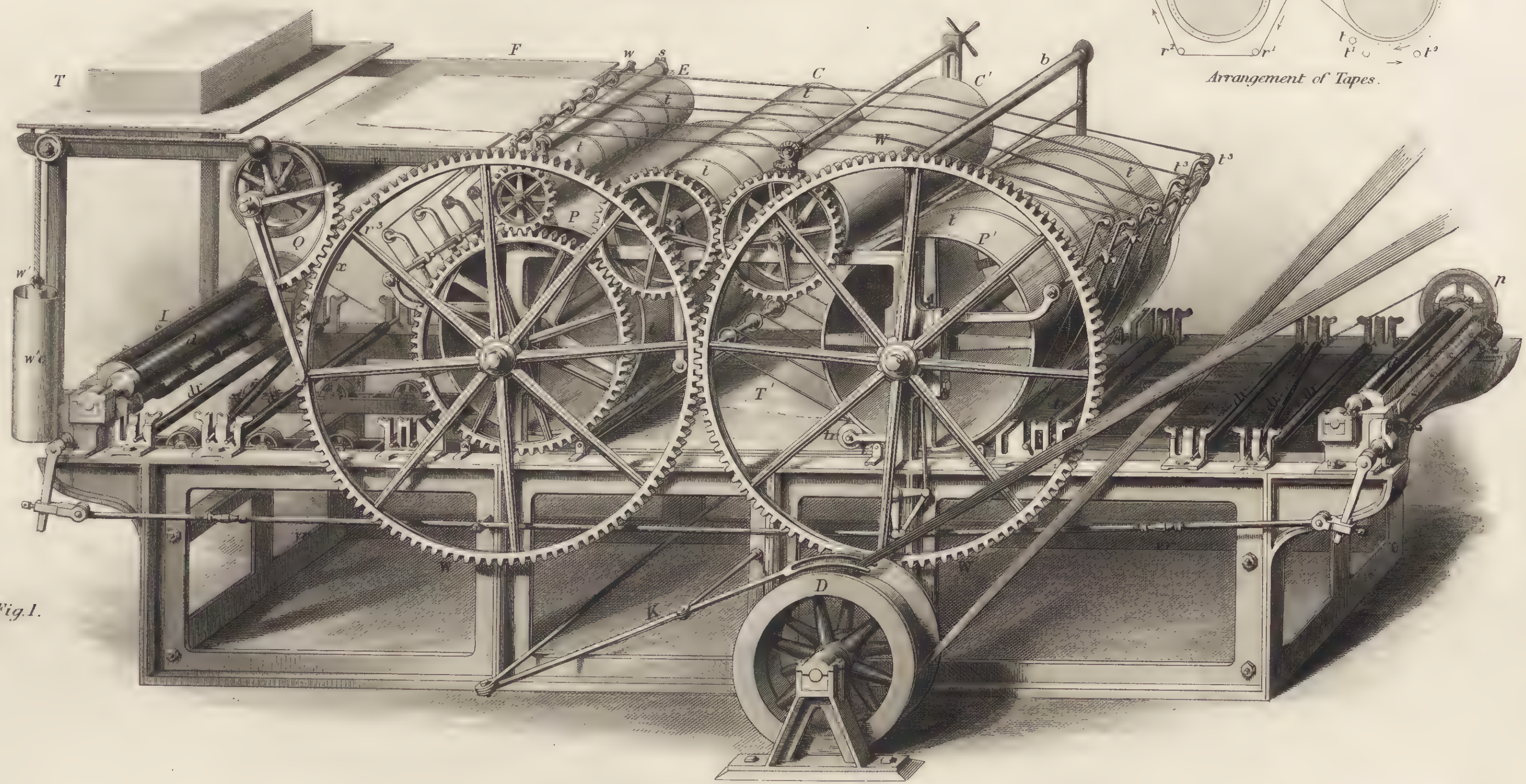


Fig. 1.

PRINTING. — DOUBLE CYLINDER PRINTING MACHINE.

sheet. A little variation in this respect might not be of importance in newspaper work, in which great despatch is required, but it is highly important to the appearance of the work in book-work. It is also a great advantage in newspaper-work to be able to print the first side or outer form deliberately, and to leave the making up of the inner form to the last moment, and then to work it off. In order to print both sides in register before the sheet leaves the machine, the object is to cause the sheet, after being printed on one side, to travel over the surfaces of the cylinder and drums at such a rate as to meet the types for the second side at the exact point which will cause the second side to fall with perfect accuracy upon the back of the first. To accomplish this the cylinder and drums must revolve at precisely the same speed as the carriage underneath, and any inaccuracy in the turning of the axles, the cutting of the teeth of the wheels, or other deficiency, will produce defects in the register. The ink, too, must be properly distributed, and the face of the type be perfectly covered; the inking apparatus must also be under complete control and in good working order. The various ingenious contrivances by which these objects have been attained, will be understood by referring to the steel engraving, and to the following description.

The blank paper, which is to be printed, is laid on a table T, by the side of which, on a raised platform, stands a boy, called the *layer-on,* who places the paper, a sheet at a time, upon the feeder F, which has a number of linen girths or tapes passing across its surface, and extending to a roller at each end of the feeder, so that when the rollers are partially turned round, the motion of the girth carries the sheet forward under the web roller w and the smoothing roller s, and delivers it over the entering drum E. The partial revolution of the feeder is accomplished by attaching to its axis the small quadrant Q; this is raised by means of the large wheel W, to the side of which is a toothed segment x, so that for every revolution of the large wheel the quadrant is made to revolve through a space sufficient to cause the feeder to carry in the sheet, and when the toothed segment has passed the quadrant, the latter falls down again, ready to be raised as the wheel comes round. By this means, provided a sheet of paper be placed upon the feeder once during every revolution of the large wheel, the quadrant takes it into the machine at the right moment, and thus prevents it from occupying a wrong position or interfering with the sheet which is actually being printed. The feeder, then, delivers the sheet of white paper to the entering drum E, where it is seized between two systems of endless tapes, which pass over a series of rollers to keep them extended. These tapes are so contrived as to fall between the pages of the printing and on the margins or edges of the sheet: this allows them to remain in contact with both sides of the sheet during its entire passage through the machine, and in this way the paper is conveyed from the printing cylinder P to the other printing cylinder P′ without disturbing the *register* or coincidence of the pages on opposite sides of the sheet. The printing cylinders are of iron turned quite true, and are covered with *blankets* of fine woollen cloth: they are mounted on strong axes, which turn in bearings attached to the main frame of the machine. These bearings can be adjusted by means of screws to suit the amount of pressure required. The sheet is conveyed from one printing cylinder to the other by means of the conveying drums C C′, which are of wood. The cylinders and drums are all connected by toothed wheels, so as to ensure a uniform and steady motion. The conveyance of the sheet with accuracy and speed by means of the tapes is an important feature of this machine. One system of tapes may be said to commence at the feeding apparatus F: from this they proceed in contact with the right-hand side and under portion of the printing cylinder P: they then pass over the conveying drum C and under the conveying drum C′, whence they proceed to encompass the left-hand side and under portion of the printing cylinder P′, and by passing in contact with the small rollers $r\, r'\, r^2\, r^3$ they arrive again at the feeder F, thus forming one of the series of endless tapes. This is shown by the continuous line in the diagram Fig. 2 of the steel engraving. The other system of tapes corresponds with the first in number and position in such a way, that the sheet of paper, so long as it is grasped between them, may be held securely and yet be in constant motion. Commencing with this second system of tapes at the feeding apparatus, they descend therefrom to the entering drum E, where they meet and coincide with the first system in such a manner as to proceed together under P, over C, under C′, and round P′, until they arrive at the roller t^2, where they separate. From the roller t^2 the tapes descend to the rollers $t'\, t^2$, and proceeding up to the stretcher t^3, pass under or over the supporting bar b, and proceed to the point from whence they commenced. The dotted line in Fig. 2 of the steel engraving will show the arrangement of the second system of tapes.

The two forms of type required to print the sheet on both sides, are placed at a certain distance from each other on a long carriage, and close to each form is an inking table consisting of an extended metal surface also supported by the carriage. The carriage moves backwards and forwards from one end of the machine to the other on rollers attached to the main frame of the machine, and in its progress to and fro it brings the types at the proper moment in contact with the sheet of paper on one of the printing cylinders. This reciprocating movement is produced by a pinion working into the alternate sides of a rack under the tables, and motion is given to the pinion by bevel wheels. The mechanism for supplying the proper quantity of ink, for distributing it equally over the inking-table, and then applying it to the types, is ingenious and effective. There is of course a complete set of inking apparatus attached to each form. The metal roller d, called the ductor roller, has a slow rotatory motion imparted to it by means of a catgut band passing round two pulleys, one of which, p, is attached to the axis of d, and the other to the axis of the

printing cylinder P′. A horizontal plate of metal, the edge of which is ground straight, is adjusted by screws, so as to be nearly in contact with the ductor roller; and a back being put to the horizontal plate, the whole forms a sort of trough I for containing the mass of ink, and as the metal roller revolves, it becomes covered with a thin film of ink. An elastic composition roller, called the *vibrating roller*, shown at *e*, in Fig. 3, is by means of the rods *v r*, *v r*, moved by a small cam attached to one of the large wheels W, made to vibrate between the ductor roller and the inking table. When the vibrating roller rises, it comes in contact with the ductor roller, takes from it a small portion of ink, and descending, deposits it on the inking table. Three or four rollers of smaller diameter *d r*, called *distributing rollers*, are placed somewhat obliquely across the machine. The spindles of these rollers are made long, and they lie in notches, and not in fixed bearings. As the table moves under them, they not only rotate, but have also a motion in the direction of their length in consequence of their oblique position, and this compound motion produces a perfect distribution of the ink on the inking table. The inking table then passes under 3 or 4 inking rollers *t r*, to which it conveys the distributed ink, and they in their turn ink the type *f;* so that every time the type passes to and fro, that is, every time a sheet is printed, the form *f* is touched no less than 8 times by the inking rollers. The distributing rollers *d r*, and the inking rollers *t r*, all turn in notched bearings so as to allow them to move up and down, in order that they may bear with their weight on the inking table and the form: hence they require no adjustment by screws, but are ready for work by being dropped into their notched bearings. The machine is put in motion by a strap proceeding from a rigger and round the drum D, which has a fast and a loose pulley. The strap can be shifted from one to the other by means of the forked lever *k*, which is under the command of the feeding-boy, so that the machine can be set going or stopped in an instant. These machines require no very great power to turn them. Messrs. Clowes of Stamford Street found two five-horse engines sufficient to work twenty of these machines.

It is scarcely necessary, after the above description, to state the working of this machine. The sheets of blank paper are placed one by one on the feeder F. The feed-rollers are made to move by means of a segmental wheel Q, which advances the sheet of paper sufficiently to allow it to enter between the two systems of endless tapes at the point where they meet each other on the entering drum E. As soon as the sheet is fairly between the tapes, the feed-rollers are, by the operation of a weight *w′*, contained in the weight-case *w′ c*, drawn back to their original position, ready to advance another sheet into the machine. As the sheet is carried along between the endless tapes, it applies itself to the blanket on the printing cylinder P, and as it revolves, it meets the first form of types, and receives the impression from it. The sheet, now printed on one side, is carried over C and under C′ to the blanket on the printing cylinder P′, where it is now in an inverted position, with the printed side in contact with the blanket, and the white side outwards, and this, upon meeting the second form of types at the proper instant, receives the second impression, and completes the sheet. On arriving at the point where the two systems of tapes separate, the perfect sheet is thrown out upon the table T′, where it is taken out by a boy, and arranged with the other printed sheets in a heap.

It is to a machine of this kind that we are indebted for most of the cheap literature of the day. That which the railway, the locomotive engine, and the steam-boat have done for locomotion and traffic, the printing-machine has accomplished for education and intelligence. Without the printing-machine, cheap literature could not have existed; English Bible Societies could not have scattered in such prolific abundance the word of God over the world, and the newspaper-press—that true exponent of a free people—must have remained comparatively ineffective.

The printing-machine, however, such as we have described it, proved inadequate to the demand for newspapers. In 1827, Messrs. Cowper and Applegath conjointly invented the *four-cylinder* machine, which Mr. Applegath erected for printing the *Times* newspaper. That it immediately superseded König's machines will readily be supposed, when it is stated that the latter produced only 1,800 impressions per hour, while the former prints from 4,000 to 5,000 impressions within the same time. Fig. 1753 will convey a general idea of these machines, which are still used at the *Times* office for printing the *Supplement*, or for that form of the paper containing advertisements, &c., which allows of more time in the preparation and working than the form which includes parliamentary debates, latest intelligence, &c. Each of these machines consists of a table *a*, moved backwards and forwards under the 4 iron cylinders *b*, called the *paper* cylinders; these are each about 9 inches in diameter, and are covered with *blanket*. The sheets of paper are held round these cylinders by means of tapes, as already described. The form of types is fixed on one part of the table *a*, the inking rollers *c* occupy another part of the table, on which they distribute the ink; *d* is the ink-trough; *e* is the elastic roller vibrating between the ductor roller and the table. This machine is fed by four boys, named *layers-on*, who lay the sheets of paper one at a time on the feeding-boards *f*, whence they enter the machine between 3 pairs of tapes, by which they are conveyed round the cylinders, and thence to the positions *g g*, where four boys named *takers-off* stand, who receive the printed sheets as the tapes separate.

Machines of this kind continued to supply the *Times* until the year 1848. The increased supply which they afforded stimulated an increased demand; nor need we feel surprised that a journal conducted with so much intelligence and honesty of purpose, written with so much skill—often, indeed, amounting to genius,—that a journal which has long proved itself

to be the consistent advocate of the poor, the injured, and the oppressed, and the unflinching opponent of the selfish, the unjust and the mean; that such a journal, shedding not only an informing light on the politics and news of the day, but advocating with a master-hand the claims of literature and science, the fine arts, and the useful arts,—of everything, in short, that is calculated to advance civilization, and to promote the dignity and happiness of the human race,—we cannot wonder, we repeat, that the circulation of such a paper should be to a great extent limited only by the power of multiplying the number of its copies. The increased demand was met by Mr. Applegath by the invention of an entirely new machine, which we now proceed to describe. But before doing so, it is necessary to state in what consisted the limit of speed in the former machine. It will be seen on reference to the steel engraving, and

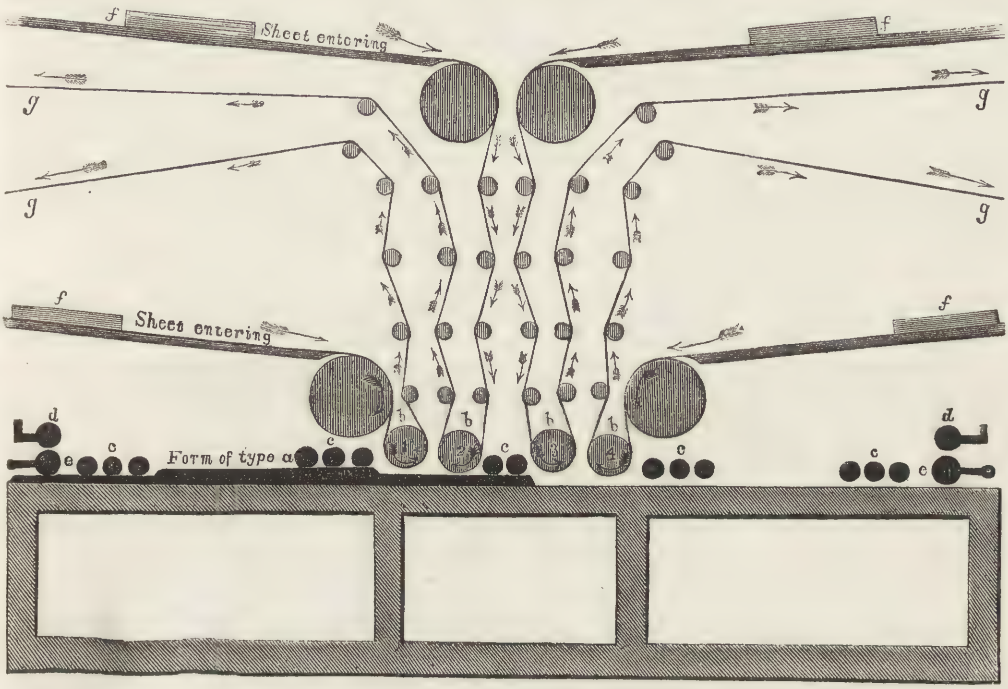


Fig. 1753. APPLEGATH AND COWPER'S *Times* MACHINE.

to Fig. 1753, that the forms of type and the inking table have to travel backwards and forwards for each revolution of the paper or printing cylinder—backwards to be inked, and forwards to be printed. In the *Times* machine, the frame has a motion of 88 inches in each direction. Now it is evident that in the reciprocating motion there must be two dead stops for every revolution of the printing cylinder, and if the machine be worked at a high rate of speed, the momentum acquired by the heavy metal table must render it liable by its sudden stoppage to rupture some part of the apparatus. It was found, moreover, that in sheets of so large a magnitude as those employed in printing the *Times*, each layer-on could not deliver them with the required precision at a more rapid rate than 2 in 5 seconds, or 25 per minute, which is at the rate of 1,500 sheets per hour; or with 4 cylinders, and 4 layers-on, 6,000 sheets per hour. It was, however, required to produce at least 10,000 sheets per hour, and this it was found would require 7 printing cylinders, the arrangement of which in one machine presented mechanical difficulties of a very formidable kind. Mr. Applegath therefore determined to abandon the reciprocating motion of the table, and to adopt a continuous circular motion. We may suppose his first crude idea to have been to set up the old machine on one of its sides, so that instead of the drums and cylinders moving on horizontal axes, they should move on vertical axes. In the machine as it actually exists, there is a central drum, Fig. 1754, 200 inches in circumference, or 64 inches in diameter, capable of moving on a vertical axis. The inking table and the columns of type are secured to the surface of this drum: the columns of type are placed vertically, not conforming to the curve of the drum, but forming the sides of a polygon, the axis of which coincides with that of the drum. This is contrived in the following manner:—A slab of iron is curved on its under side, so as to fit the large cylinder, while its upper surface is filed into facets or flat parts, corresponding in width and number to the width and number of the columns of the newspaper; between each column there is a strip of steel, with a thin edge to print the "rule"—the body of this strip being wedge-shaped, so as to fill up the angular space left between the columns of type, and to press the type together sideways, or in the direction of the lines; the type is pressed together in the other direction by means of screws, and is therefore firmly held together. The surface of the type thus forms a portion of a polygon,

as already noticed; and the regularity of the impression is obtained by pasting slips of paper on the paper cylinders. The large central drum is surrounded by 8 cylinders, each about 13 inches in diameter, also with vertical axes. They are covered with cloth, and upon them the paper to be printed is carried by means of tapes. Each of these cylinders is so connected with the central drum by means of toothed wheels, that the surface of each must move with the same velocity as the surface of the drum. It will thus be evident, that if the type on the drum be inked, and each of the cylinders be properly supplied with a sheet of paper, a single revolution of the drum will cause the 8 cylinders to revolve also, and produce an impression on one side of each of the sheets of paper. But for this purpose it is necessary that the type be inked 8 times during one revolution of the drum. This is accomplished by means of 8 sets of inking rollers, one for each paper cylinder. The ink is held in a vertical reservoir (supplied from above), formed of a ductor roller, against which rest two straight-edges connected at the back, so as to prevent the ink from running out. It is conveyed from the ductor roller by one of the inking rollers in the following manner:—As the inking table on the revolving drum passes the ductor roller, it receives from it a coating of ink; and then coming immediately in contact with the inking rollers, it inks them; the types next follow and receive from the inking rollers their coating of ink, and the drum, still revolving, brings the inked type into contact with the paper cylinders, and the sheet is printed. It must not be forgotten as one of the distinguishing features of this machine, that the various processes

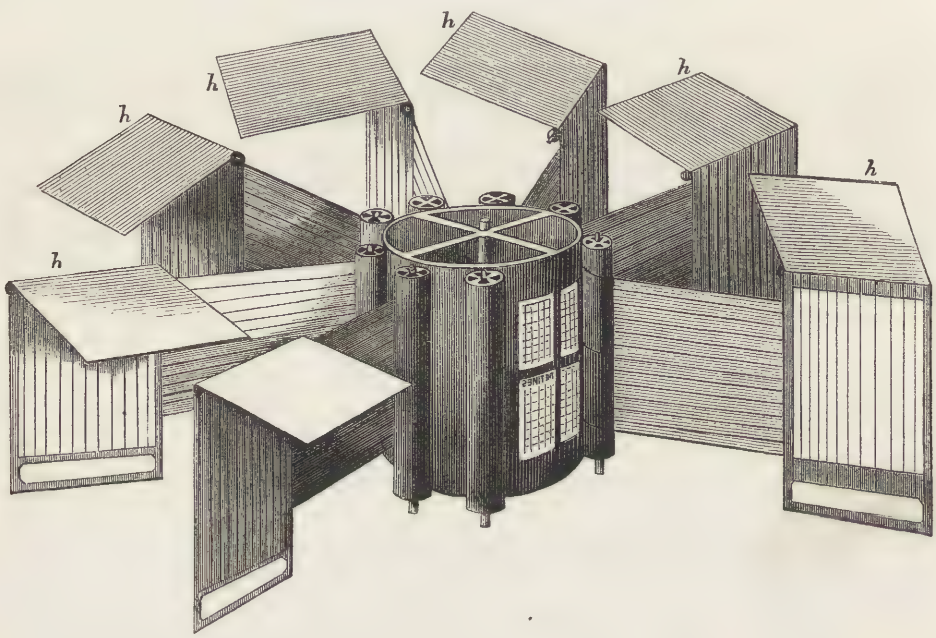


Fig. 1754. APPLEGATH'S *Times* VERTICAL PRINTING-MACHINE.

which have just been enumerated for one set of inking rollers, and one paper cylinder, are repeated 8 times for every single revolution of the central drum, so that in this period 8 sheets are printed, and turned out of the machine. For this purpose it is necessary to supply the 8 cylinders each with a sheet of paper. Over each cylinder is a sloping desk, *h*, upon which a number of sheets of white paper are placed. The layer-on stands by the side of this desk, and pushes forward the paper a sheet at a time towards the tape fingers of the machine. These tapes seize it and draw it down in a vertical direction between tapes in the 8 vertical frames until its vertical edges correspond with the position of the form of type on the drum. When in this position its vertical motion is arrested for a moment, it then moves horizontally and is carried towards the printing cylinder by the tapes. Passing round this cylinder, it is instantly printed. It is then conveyed horizontally by means of tapes to the other side of the frame, and is moved along to another desk, where the taker-off pulls it down. As soon as one sheet is thus disposed of, accommodation is made for another, and as each layer-on delivers to the machine 2 sheets every 5 seconds, 16 sheets are thus printed in that brief space, and this is continued for any length of time, supposing no accident occurs, such as a sheet going wrong, in which case it is the duty of the taker-off to pull a bell handle, and the machine is instantly stopped by the engineman. As the type form on the central drum moves at the rate of 70 inches per second, and the paper to be printed moves at the same rate, if by any error in the delivery or motion of a sheet of paper it arrive at the printing cylinder $\frac{1}{70}$th of a

second too soon or too late the relative position of the columns on one side as compared with those on the other side of the paper will be out of register by $\frac{1}{70}$th of 70 inches, viz. 1 inch, in which case the edge of the printed matter on one side will be an inch nearer to the edge of the paper than on the other side. By inaccuracy in the delivery of the paper to the machine, we do not mean that each layer-on must deliver his sheet at the right instant of time; this would lead to strange irregularities and render fast printing impossible. No; all he has to do is to draw forward the sheets so as always to have the edge of one ready for the machine to take in, which it does by the mechanism which we are about to describe in the following detailed account. If the steam engine which works the machine be put on a greater speed, the central drum and all the attendant apparatus would work with greater rapidity, and such a speed might easily be attained as to render it impossible for the layers-on to present the paper fast enough to satisfy the improved appetite of the machine; but in any case the machine would not take in the sheets *as* the layers-on chose to present them, but only at those periods, rapidly recurring though they be, which are provided by the peculiar functions of the machine. There is in fact an apparatus provided, the function of which is similar to the segmental wheel Q, noticed in the description of the two-cylinder machine. In the following figures the same letters of reference refer to the same parts of the machine.

a, *a*, is the large vertical drum, forming the centre of the system, mounted on the shaft *b*, *b*, and driven by the bevel wheel and pinion *c*, *d*, the shaft of the pinion *d* being supported on the floor, and carried to the prime

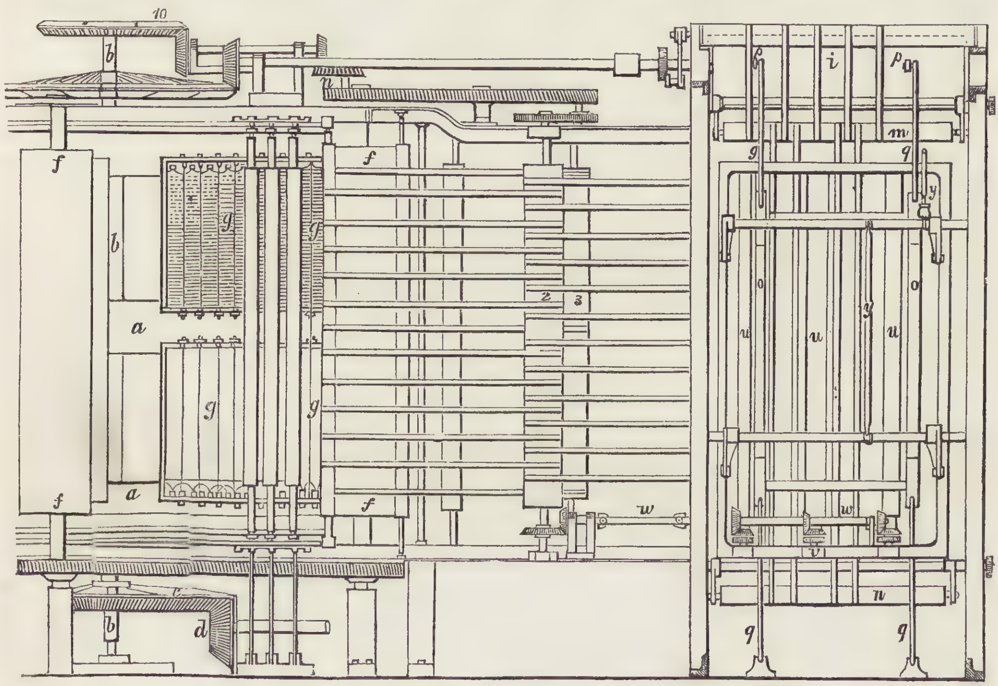


Fig. 1755. ELEVATION.

mover, which in this case is a direct action or disc steam engine. *f f*, are the 8 impression cylinders, driven by the spur wheel *e*; the same speed is therefore secured between the circumference of the drum (with the type) and the circumference of each impression cylinder. The columns of type, as already mentioned, are fixed in the four type holders *g*, *g*. Between the columns of type are the *rules*, which are fitted into the top and bottom of the type holder in a similar way to a metal saw in its frame. These rules are made like the keystone of an arch, to fill up the space left at the junction of the columns, owing to the angle which the columns form with each other in their position as sides of a polygon. In order to avoid the possibility of the type escaping from its place, in screwing it up, the centre rule in the type holder is a fixture; and each column is jammed up from one end by a set-screw, as shown at top and bottom of the upper and lower type holders, Fig. 1755. The four pages of type thus prepared are bolted to the rings of the central drum. It will be observed that the impression cylinders are not arranged symmetrically around the central drum. A greater space is left between one pair than between the others, in order to give room to get at the type, which can only be done when it is in the position shown in Fig. 1754.

One of the systems of apparatus for supplying the impression cylinders with sheets of paper, is shown in Fig. 1757. This will enable the reader to understand how the paper is brought to a vertical position, and moved laterally in its passage through the machine. The sheets of paper are piled on the feeding board *h*, Figs. 1754, 1757, and are pushed forward, one by

one, by the layer-on, over the centre of the feeding drum *i*, Fig. 1755, *k*, *k*, are two small fluted rollers, fixed on the dropping bar, and driven by tapes off the roller *l*. At the right moment this bar turns on its centre *l*, and *k k* drops, as shown in the figure, and by its motion advances the sheet of paper between the rollers *i* and *l*. The motion of the sheet is then continued downwards by tapes passing around the rollers *m*, *m*, and *n*, *n*. The paper is steadied in the frame. The rollers *m*, *m*, and *n*, *n*, and the tapes with them, open, and leave the sheet in its vertical position, held up by the stoppers. The opening of the rollers *m*, *m*, and *n*, *n*, is effected by their bearings being mounted in the ends of levers, and these levers are made to act upon each other by means of the toothed segments shown in the figure. The cam *r* lifts the link *s*, which moves the top pair of rollers *m*, *m*, while the motion is conveyed to the lower pair,

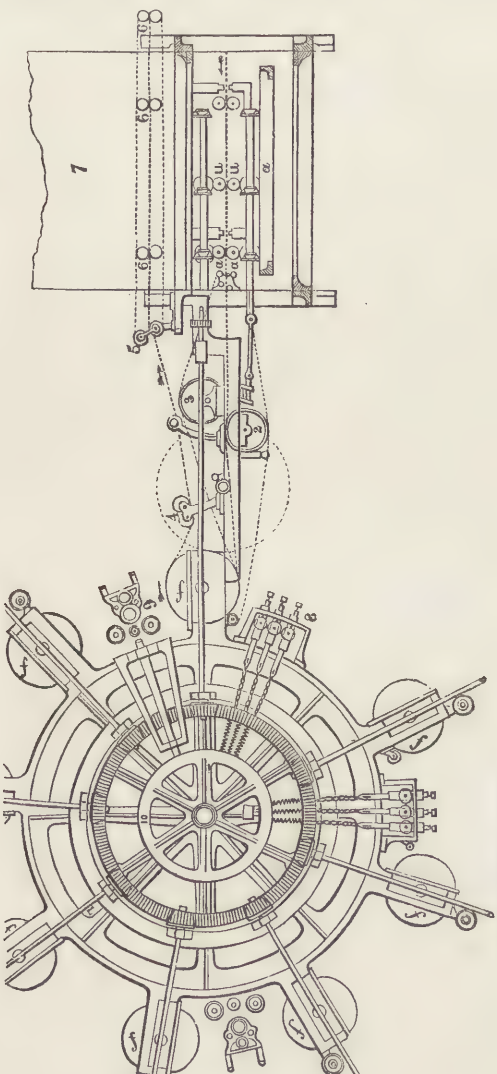


Fig. 1756. PLAN.

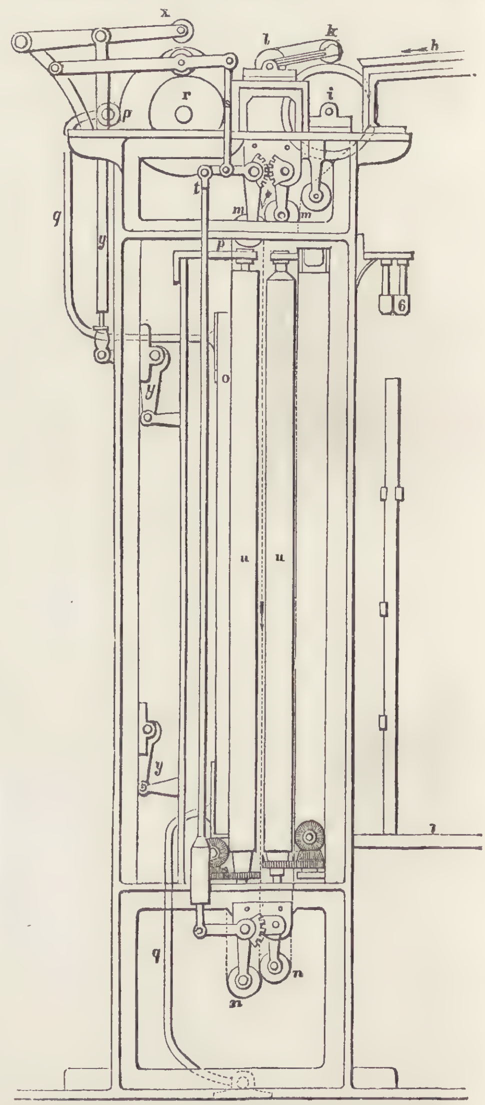


Fig. 1757. END VIEW OF THE FEEDING APPARATUS.

n, *n*, by the connecting rod *t*, which is loaded with a weight at bottom to keep the friction roller on the cam *r*. The sheet of paper being held up by the stoppers, the latter are now relaxed, and the weight of the paper is taken by two pairs of small fingers, or suspending rollers, at the top of the sheet, which are brought together by a cam, and, pressing slightly together, hold the sheet up during the instant of time that the stoppers are relaxing, and until the three pairs of vertical rollers *u u*, *u u*, *u u*, Figs. 1755, 1757,

whole of its course by numerous tapes, only a few of which are represented. The down tapes pass round the feeding roller and the smaller rollers *m*, *m*, and *n*, *n*, and carry the sheet with them until its progress is arrested by two long narrow strips of wood *o*, *o*, covered with woollen cloth, and called "stoppers," one pair of which is advanced forward against the other pair, which is fixed. The motion of this stopper frame is effected by means of the cam *p*, Fig. 1757, which acts upon the arms *q q*, *q q*, attached to the

are brought into contact to communicate the lateral motion to the sheet. The vertical rollers are all driven at the same speed as the printing drum by means of bevel wheels and pinions, as shown. The three front rollers, *u*, *u*, *u*, are mounted in a hanging frame *v*, *v*, and the pinions at bottom are driven through the bevel pinions and the shaft *w*, *w*, which is made with a universal joint to allow of the motion of the frame *v*, *v*. The back rollers are driven in a similar way, but their centres are stationary.

The proper motion is communicated to the hanging frame *v*, *v*, by a cam, similar to *p*, acting upon the lever and friction pulley *x*, the motion being communicated through the levers *y*, *y*, Fig. 1757. Immediately on the rollers being brought into contact with the paper, it is advanced by their motion into the mouth of two sets of horizontal tapes, which pass round the drums 2 and 3, (also driven by gearing,) and carry the sheet onwards towards the impression cylinder *f*, where it is printed, and whence it returns in the direction of the arrows, the dotted line showing its path. The sheet of paper in its passage out meets with another set of endless tapes at the roller 4, Fig. 1756, which assist it out as far as the roller 5, where these tapes return and leave the sheet to complete its course by the action of a single pair of suspending tapes at the top of the sheet, and pressed lightly together by the pulleys 6. On arriving at the outer pulley these tapes are forcibly pressed together by a lever and stopped, and thus hold the sheet of paper suspended and ready for the taker-off to draw down, and place on the taking-off board 7—an operation very easily performed.

The method of counteracting the deviation of the faces of the columns of type from a true circle is as follows: strips of paper are pasted down the impression cylinder, in width equal to each column. Other narrower strips of paper are pasted in the centre of these, and other strips, narrower still, until the surface of the impression cylinder becomes a series of segments of smaller circles, agreeing sufficiently with the required curve to produce a perfect impression of the type over the whole width of the column.

The ink is supplied to the type by 3 inking-rollers (shown on the type *g g*, Fig. 1755), between each 2 impression-cylinders. These rollers receive their ink from revolving in contact with a curved inking table, placed on the central printing drum opposite to the form of type. The ink is communicated to the inking table by two vibrating rollers, alternately in contact with it and the ductor roller. The ductor roller 9, Fig. 1756, forms one side of an ink-box from which, as it revolves by the bevel gearing, 10 and 11, it withdraws a portion of ink. The two ink-boxes are kept full by a reservoir placed above them. The inking rollers are caused to press in contact with the inking table by means of coiled springs, as shown, and their brass bearings are also furnished with set-screws to hold them in close contact with the type, as it passes, in a similar manner to other quick machines. The spindles of the inking rollers are also provided with small friction wheels at top and bottom, which run upon a brass bearer on the central drum; by which they are kept from being drawn into the drum by their springs, except at the proper time. There is an advantage incidental to the vertical position of the type and the paper; viz., that the ink does not sink into the type as it does when it is placed horizontally, and on that account the type is kept much cleaner.

In looking at a copy of the *Times*, it will occasionally be observed that the impression is not exactly in the centre of the paper. Now, the only wonder really is, that it should be so nearly true. The type and the paper move at about the rate of 6 feet per second, so that an error in the arrival of a sheet of paper to the impression cylinder of $\frac{1}{76}$th of a second would cause an error of 1 inch in the margin. Yet so accurately is this performed, that the waste of sheets is considerably less with this machine than with the old horizontal ones.

Some little difficulty was experienced at first in carrying on the paper, when vertical, without buckling it. This difficulty was conquered by introducing an additional roller, to give the paper a slight angle, instead of drawing it out in a straight line, which had the effect of stiffening it, on the same principle as corrugating a plate of iron.

The produce of this machine might readily be doubled, by having two forms of type on the central drum, instead of one, and if there were not space for two machines, the additional eight laying-on boards and feeding drums might be made in a story above the present ones.[1]

The following are interesting statistics relative to the printing of the *Times*:—On the 7th of May, 1850, the *Times* and *Supplement* contained 72 columns, or 17,500 lines, made up of upwards of 1,000,000 pieces of type, of which matter about $\frac{2}{5}$ths were written, composed, and corrected after 7 o'clock in the evening. The *Supplement* was sent to press at 7.50, P.M., the first form of the paper at 4.15, A.M., and the second form at 4.45, A.M.; on this occasion 7,000 papers were published before 6.15, A.M., 21,000 papers before 7.30, A.M., and 34,000 before 8.45, A.M., or in about four hours. The largest number of copies ever printed in one day was 70,000, and this was on the 14th of November, 1852, the day after the Duke of Wellington's funeral. As there was no supplement on this day, the whole of the impression was printed at the two vertical machines, one of which now prints 11,000 per hour, and the other 12,000 per hour, not including stoppages. The whole of this enormous impression was worked without once washing the rollers or brushing the form. As such numbers as these may not convey to every reader an adequate idea of the enormous amount of material consumed in the publication of this wonderful journal, we may

(1) Mr. Applegath's machine was described by the late Professor Cowper, in Mr. Weale's "London Exhibited," 1851. There is also a carefully prepared account of the machine in the *Artizan*; and in the *Mechanic's Magazine*, No. 1509, is an account of Mr. Applegath's new vertical machine, which is capable of printing 16,000 per hour. We have to thank Mr. J. Applegath, of the *Times* office, for his attention to our wishes during several visits to his brother's printing machine.

state, that the paper for a week's impression fills 13 waggons; and that the whole of one day's impression, taking it at 42,750 copies, weighs about $7\frac{1}{2}$ tons.

Section VI.—Stereotyping.

It will be seen, by reference to a former Section, how numerous and complicated are the processes required in the preparation of the two forms of a printed sheet. The type previously distributed has to be composed, and the pages imposed; a proof is taken and read; the errors marked thereon are corrected; a second proof is taken and read, and the errors are corrected; then there is the author's proof, and the press proof: we have, in fact, a number of persons all interested in detecting blunders, and when at length the sheet is pronounced correct, and is sent to press, a small number only may be required, such as 250, 500, or 750. This number being worked, the forms are unlocked, and the type is distributed; so that all this care and anxiety bestowed upon every sheet of the work, must be bestowed again (with the exception perhaps of the author's proof) if the work is required to be reprinted.

The great majority of works, however, which issue from the press, never attain the honour of a reprint or a second edition, while there are other works for which there is a constant daily demand. This was found to be the case soon after the invention of printing, and the plan adopted by the continental printers was to set up the whole of the work which was in request, and to keep the type standing for future editions. This enabled the printer to work off as many copies at a time as he had demand for, and so not encumber his warehouse with useless stock; and it also enabled him to sell the work at a very much cheaper rate than if the type had to be composed, &c. for each edition. The disadvantages of the plan were the large outlay for type, the space occupied by the forms, and the liability to damage from the dropping of letters, batters, and other accidents. Attempts appear to have been made early in the 18th century to cement the types together at the bottom with lead or solder, in order to their more perfect preservation. Camus states,[1] that in June 1801 he received a letter from the Luchtmans, booksellers of Leyden, with a copy of their stereotype bible, the plates for which were formed by soldering the bottom of common types together with some melted substance to the thickness of about 3 quires of writing-paper; and they add, "these plates were made about the beginning of the last century by an artist, Van der Mey, at the cost of our late grandfather, Samuel Luchtman, bookseller."

This, however, does not appear to us to be a case in point. The art of stereotyping[2] consists in making perfect fac-similes in type-metal of the face of the pages composed in moveable types. These fac-similes being made, the type is released, and may be distributed and serve for the setting up of fresh pages, which may again furnish, as it were, the punches to the mould into which the type-metal is poured for the purpose of making the fac-simile. The great value and distinguishing feature of stereotyping is, that the type is released, whereas, in Luchtman's process, it is sacrificed, and cannot be distributed or used again for any other work. The first person who appears to have suggested the casting of plates from the pages of type was William Ged, a goldsmith of Edinburgh, who, about the year 1725, being in company with a printer, who was lamenting the want of a good letter-founder in Scotland, Ged suggested the multiplication of the composed and corrected pages by means of casts; so that a small stock of type might serve for the perpetuation of a large number of works. He soon after produced a specimen of the new art, but wanting capital to perfect and carry out the idea, he made certain proposals to a man of property, who looked into the plan, but retained his money in his own safe keeping. Ged then visited London, and sought the patronage of the London stationers; he was encouraged with words, but received no substantial assistance. He next submitted his scheme to the Universities and to the king's printer, and met with the support which he required. He stereotyped some bibles and prayer-books, and the sheets worked off from his plates were admitted to be equal to the printing of the day. But now, while the success of his scheme appeared certain, new difficulties arose. The argument used by the idol-makers of old,[3] "Sirs, ye know that by this craft we have our wealth," and that, "this our craft is in danger to be set at nought," was, as is usual in such cases, urged against this most useful and important invention. The compositors refused to set up works for stereotyping, and even those which were set up, however carefully read and corrected, were found to be full of gross errors. The fact was, that when the pages were sent to be cast, the compositors or pressmen, bribed, it is said, by a type-founder, disturbed the type and introduced false letters and words. Poor Ged died, and left the dangerous secret of his art (which he did not disclose during his life-time) to his son, who, after many struggles for success, failed as his father had done before him; and yet the very men who were the loudest in their cry, "Great is Diana of the Ephesians!" —who had rejected Ged's plans—now used his plates, although they knew not how to produce more. Illiberal policy is always short-sighted. If Ged's opponents had been less selfish, they might have foreseen that the new art would have increased the demand both for type-founders and for compositors, as it has done since its general adoption. Indeed, if it were not for stereotyping, a large number of valuable works would rapidly go out of print; bibles and prayer-books

(1) "Histoire et Procédés du Polytypage et de la Stéréotypie." It appears from this work, that about the year 1735 the French made use of casts of the calendars placed before their church-books. A specimen of one of these plates, examined by Camus, an impression from which is given in his work, was of copper, $3\frac{1}{2}$ inches long, 2 inches broad, and $\frac{1}{7}$th inch thick. From the roughness of the casting it appeared to have been made in a mould of sand or clay. The back had been dressed with a file, and then attached to a block of wood.

(2) Στερεὸς, solid; τύπος, a type. (3) Acts xix. 25, 27.

could not be produced in such vast numbers, and at so cheap a rate as they now are, and the continued sale of such works as the present Cyclopædia would be impossible. The effect of the opposition to Ged's invention was to cause the art to be forgotten for half a century. It was then revived by Dr. Tilloch, who contrived a method for producing stereotype-plates, and printed several volumes with them. The art was not, however, of much practical value, until Lord Stanhope took it up: he engaged the services of a London printer, named Wilson, and at length matured the plan such as it is at present practised.

The type employed in stereotyping differs somewhat from that in common use. The letter should have no shoulder, but should rise in a straight line from the foot: the spaces, quadrats and leads are of the same height as the stem of the letter, the object being to diminish the number and depth of the cavities in the page, and thus lessen the chances of the mould breaking off and remaining in the form. Each page is carefully corrected, and imposed in a small chase with metal furniture, which rises somewhat higher than the type. The number of pages in the form may be 1, 2, 3, or more, according to the size of the book; the smaller the page, the larger the number. The surface of the type is next rubbed over with a soft brush holding a small quantity of very thin oil. Plumbago is sometimes preferred. A brass rectangular frame of three sides with bevelled borders adapted to the size of the pages is placed upon the chase so as to inclose three sides of the type, the fourth side being formed by a single brass bar having the same inward sloping bevel as the other 3 sides. The frame thus formed, Fig. 1758, serves to define the area and thickness of the cast, which is next taken in plaster-of-paris, for which purpose two degrees of fineness of

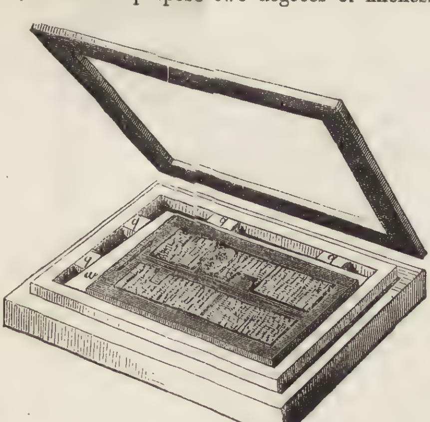


Fig. 1758.

plaster are used; the finer quality is mixed, poured upon the surface of the type, and gently worked in with a brush so as to ensure contact and exclude air bubbles. A large quantity of the coarser plaster mixed with water is then poured and spread over the previous layer, but without disturbing it. A straight-edge is passed over the moulding frame, to clear away the superfluous plaster and leave that in the frame of uniform thickness. The plaster mould soon sets, and the mould-frame is raised and the mould comes off from the surface of the type, the film of oil or plumbago preventing the adhesion of the plaster. The plaster mould is dressed and placed on its edge in one of the cells of a sheet-iron rack contained in an oven, and exposed to the temperature of at least 400° for about 2 hours, when it becomes perfectly dry. A good workman will mould 10 sheets 8vo. or 160 pages in a day: each mould generally contains 2 pages 8vo. The mould is now very friable and must be handled with delicacy; it is placed with the face down upon a flat cast-iron plate called the *floating*-plate: this is placed at the bottom of a square tray of cast-iron with the upright edges sloping outwards, called the *dipping-pan*, Fig. 1759. A cast-iron lid is applied to it and secured by a screw s, and shackles *s' s'*. The pan is heated to 400° before the plaster mould is put into it, and is next plunged into an iron pot

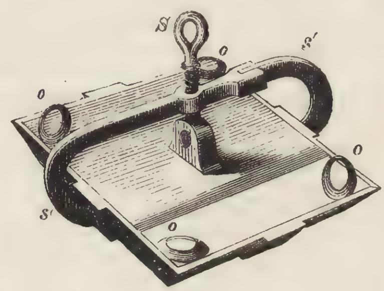


Fig. 1759.

placed over a furnace, containing the melted alloy, the pan being slightly inclined to allow the air to escape. There is a small space between the back or upper surface of the mould, and the lid of the dipping-pan, and the fluid metal on entering into the pan through the corner openings *o o*, *floats* up the plaster together with the iron plate (hence called the *floating plate*) on which the mould is placed, the effect of which is that the metal flows through the notches cut in the edge of the mould and fills up every part of it, forming a layer of metal on its face corresponding to the depth of the border, while only a thin metal film is left on the back of the mould. The dipping pan is suspended, plunged in the metal, and removed, by means of a crane, and when taken out it is put into a cistern of water upon bearers so arranged that only the bottom of the pan is in contact with the surface of the water. The metal thus sets from below, and remaining fluid above, it maintains a fluid pressure during the shrinking which accompanies the cooling. As it thus contracts in volume, melted metal is poured into the corners of the pan for the purpose of keeping up the fluid pressure on the mould and thus obtaining a good and solid cast. If the pan were left to cool more slowly, the thin film of metal at the back of the inverted plaster mould would probably solidify first, and thus prevent the fluid pressure which is required for filling up all the lines of the mould. A good workman will make 5 dips, each containing 2 pages 8vo., in the course of an hour, or

about $9\frac{1}{2}$ 8vo. sheets per day. When the pan is opened, the cake of plaster and metal is taken out and beaten upon its edges with a mallet, to remove superfluous metal. The stereotype plate is then taken by the *picker*, who planes its edges square, turns its back flat upon a lathe to the required thickness, and removes any minute imperfections occasioned by specks of dirt or air bubbles left among the letters in casting the mould. If any of the letters are damaged they are cut out, and separate types soldered in instead. The plate is now ready for working, and when made up with the other plates into the proper form it may be worked either at press or by machine.

In January 1816, Professor Cowper took out a patent for curving stereotype plates, fixing them on a cylinder, and printing with them. The plates were heated to prevent them from cracking in the bending. The inking apparatus had no end motion to the rollers, but the plates passed under several rollers. The ductor roller was employed.[1]

Other methods of stereotyping or of polytyping have been contrived at different periods. In 1791, M. Carez, a French printer, adopted the following method:—A page of moveable types well locked with screws was attached to a heavy piece of wood suspended with the face downwards from a beam, and this was allowed to fall suddenly upon lead in a state of fusion, but just on the point of solidifying. In this way a punch or matrix for a whole page was obtained, and was used for making relief stereotypes by attaching it to the block of wood already referred to, and letting it fall on fusible metal just on the point of setting. In this way good *polypage* plates were obtained, but there was danger of melting the types if the lead were too hot, or of bruising them if it were too cold. After various attempts to remedy these defects, M. Firmin Didot adopted the following plan. He cast his types in a very hard alloy, composed of 30 parts lead, 30 of antimony, 30 of tin and 10 of copper. In order to increase their strength the types were not made so high as usual. A page of these types being composed and well secured in an iron frame, the face of the page was pressed into pure lead by means of a fly press. The matrix for the page thus obtained was next attached to the hammer of a stamping press, on the bed of which was placed in a paper frame a quantity of ordinary type metal in a fused state, and when on the point of setting it was rolled up into a mass and the matrix of the page being brought down upon it, a sharp and well defined page in relief was obtained. By this process of *clichage*, as it is called, the plates for Didot's edition of upwards of 200 volumes were obtained. Another but very expensive method, invented by M. Herhan, was to set up the page in letters or matrices of copper sunk instead of being in relief. The page being brought down upon type metal in a fused state, produced at once a page fit for printing. Various attempts have also been made to produce casts by pressing upon the composed type sheets of paper with whiting or some other substance between them.[2] Bitumen, gutta percha, &c., have also been employed, the former substance answering well for engravings.

Attempts have been made to abridge the labour of composing by introducing the use of types bearing whole words or syllables, under the name of *logography* or *logographic printing*. An edition of Anderson's "History of Commerce," in 4 vols. 4to, 1787-9, and some other works have been printed in this way; but the scheme adds to the complication of the case, and produces difficulties in the way of spacing. There are also other objections, and the plan has been abandoned.

(1) In our last section, the claims of Professor Cowper as an inventor of steam-printing machinery were not stated with sufficient fulness. We take this opportunity of supplying the information.

In the year 1818 Professor Cowper patented a machine, in which drums were introduced between the printing cylinders of machines for printing both sides of the sheet, which was conveyed over and under these drums in its progress from one printing cylinder to the other. The effect of this arrangement was to ensure accuracy of register by keeping a firm hold upon the sheet, and preventing it from shifting between the endless tapes by which it was conveyed. In this patent was also contained the plan of distributing the ink upon a flat table instead of upon a roller. The inking-table passed backwards and forwards under rollers, which received an end motion at the same time by means of an indentation along the edge of the table acting upon a frame in which the rollers were mounted. This apparatus solved the problem of obtaining a perfect distribution of the ink. The combination of the inking-table, and trough, and hand-roller, now in universal use, and shown in Figs. 1750 and 1751, pp. 486 and 487, is also contained in this patent. The mode of giving the end motion to the distributing-rollers on the inking-table, was simplified by Mr. Applegath, who, in 1823, took a patent for effecting this object by simply placing the rollers *diagonally* across the table instead of at right angles to its motion. This combination of the inking-table and diagonal distributing-rollers, is now in almost universal use. It is applied to machines with one, two, or four cylinders, and an equal number of feeders for printing newspapers, and it is applied, together with the conveying-drums, to machines with two cylinders and one feeder, for printing books.

(2) At a meeting of the Royal Scottish Society of Arts, 28th Feb. 1853, Dr. Daniel Wilson exhibited one of the original plates of the edition of Sallust published by Ged in the 18th century, and interesting as the first specimens of the practical application of the stereotyping process ever executed. He then detailed the various efforts at further improvement on this process—including those of Brunell, Allan, Sinclair, &c.; after which he described and exhibited the new process introduced by him to the notice of the Society, which consists in taking the casts of the types, not in gypsum or stucco, but in blotting-paper, overlaid with a thin layer of whiting, starch and flour-paste, covered with a sheet of tissue paper, and impressed on the types by means of beating it with a fine brush. It is then dried on a hot steam-chest, while still adhering to the types; and by this means a matrix is produced, and the types are again ready for distribution to the compositors within one hour. The advantages of the new process are—first, the greater certainty of the process; the new matrix not being liable to warp or break, as the stucco is. Second, the greater rapidity; the process being completed in one hour by it, which could not be done in less than six by the other. Third, the practicability of using the matrix in certain cases for casting several plates; whereas the stucco mould is always destroyed in a single casting. And, fourth, the much greater simplicity of the apparatus required; which, added to the economy of time, and the consequent diminution of the quantity of type required for the compositors, give the important economic results which form the great merit of the new plan. A mould was made, and a cast taken, in presence of the meeting; and Dr. Wilson concluded by remarking that he believed it was by the improvement and more general application of such processes as this, that the great desideratum of cheap literature was to be achieved, and not by diminishing the profits of retail booksellers, as had recently been attempted.

Section VII.—Printing in Colours and in Gold.

The early printers prided themselves not only upon the accuracy of their proofs, but also upon the beauty of their printing. Typography in superseding the scribe retained for a time the illuminator, and afte the sheets were printed, it was not uncommon to insert titles, initial letters, &c., in crimson, blue, and gold. When the illuminator ceased to find profitable employment, the printer endeavoured to imitate his labours by the use of variously-coloured inks. Hence arose that department of printing, named *Chromotypy*, one of the simplest examples of which is the printing in red of the *red letter days* in almanacs, and of the *rubric* in the Church of England Prayer Book. In these as in all other cases of letter-press printing in two colours, each form requires to be worked twice, once for the black ink and once for the red. In passing the sheets the first time through the press the red matter is omitted, the exact space which it fills being occupied by quadrats. In the second working it is difficult to preserve good register, especially as in the cases cited, where so small a portion of red is to be inserted into so large a body of black. Hence it is now usual to print red letter days in old English type in black, and the rubric in Italics, also in black.

Coloured inks require careful preparation, and before being used they must be worked up with varnish on a stone slab with a muller to the required consistency. The ink is applied to the types with a ball or a roller, the former being preferable. Suppose for example a form consists of pica, small-pica, and long-primer, each in a different colour. The prevailing colour, suppose the pica, is first worked: all the lines in pica are set up, and the other lines are filled in with small pica and long-primer quadrats. When the second set of lines is to be worked, its quadrats are taken out and the proper letters inserted, while the type of the first lines is removed and quadrats substituted; a similar plan is adopted for the third lines, and in making these changes the form must not be disturbed in its place in the press, and in this treble working of the sheet care must be taken not to disturb the points on the tympan. Nor is the paper to be allowed to dry; otherwise it will shrink, and the register cannot afterwards be obtained. If the number cannot be worked off in one day, the paper must be covered with a wet blanket and the edges slightly sprinkled.

Great encouragement was given to printing in colours by the contractors for the English State lotteries, who, shortly before the abolition of this enormous evil, issued vast numbers of ornamental handbills for the purpose of puffing off their schemes. After this time ornamental printing fell greatly into disuse, until about the year 1832, when it was revived by M. De la Rue's patent for printing playing cards. This led to great improvements in the composition and mixing of coloured inks; the art was applied to the printing of landscapes and figures, &c., in colours, and it has now attained a degree of excellence surpassing that of any former period.

In printing in gold the type is composed and made ready in the usual manner. The gold leaf is made to adhere to the paper by means of a varnish, composed of raw or burnt umber mixed with printer's varnish to the same consistency as printer's ink; this mixture is then compounded with a considerable quantity of gold size. The first mixture is necessary, as the umber will not combine with the size. The type is rolled with this compound as in ordinary printing, and the impression is taken on paper. Leaf gold is next laid over it with a piece of wool, and pressed lightly upon it. When the varnish is set the wool is rubbed roughly over the printed part, the superfluous leaf is removed, leaving the gold adhering to the varnish. To obtain good results the type should be sharp and the presswork good. Some years ago the "Magna Charta" was printed by Mr. Whittaker in letters oi gold with illuminations. The work was very superior, but the method of working was kept secret, nor was the method generally known until the publication of the Jury Report, (Class xvii.) in which it is stated as follows:—"The page is composed in movable type in the usual way: a stereotype-plate is taken. A piece of iron of the size of the page, about half an inch in thickness, is made hot and placed on the table of an ordinary typographical printing-press: the stereotype plate is then placed on the iron plate, and gets hot, and leaf gold of an extra thickness of the size of the plate, is laid very carefully on the surface of the plate: then the paper or vellum is placed on the tympan in the usual way, having been previously sifted over with dried glare of egg, and rosin finely pulverized, which adheres to it in sufficient quantity; the tympan is then turned down and the pull dwelt on. The degree of heat must be ascertained by practice; if the plate be too hot, the gold is dead and drossy; if too cold then it appears bright but imperfect. This process is similar to that now used by bookbinders in block gilding with an arming-press." [See Bookbinding, Fig. 175.]

For inferior gold printing bronze-powder is used. [See Bronzing.] The varnish is made much thicker than for gold, and after the printing, the powder being brushed over the card or paper, adheres to the printed part, and the superfluous powder can afterwards be readily brushed off. A very large trade is carried on at Manchester in the printing of ornamental tickets in gold and bronze, &c., for attaching to muslins and calendered goods. [See Calendering.] But perhaps the most remarkable instance of printing in gold, not only on account of the great size of the work, but from the short space of time allowed for it, was the *Sun* newspaper, which contained an account of the Coronation of Queen Victoria, and hence called the "golden Coronation Sun." The work was undertaken by M. De La Rue. The papers were first printed in varnish at the establishment of Messrs. Clowes in Stamford-street, and then conveyed to Messrs. De La Rue's works in Bunhill Row, where upwards of 100 persons were employed to rub on the

bronze powder. Upwards of 100,000 copies were thus produced, 10,000 of which were in time for the publication of the *Sun* on coronation day. In using this powder great care should be taken to prevent it from flying about, and being inhaled by the work-people. For want of this precaution the persons employed in the above extensive job in rubbing on the powder became afflicted with a very distressing disease in which the hair became perfectly green.

The best kind of work in this style of printing is by means of copper plates engraved deeper than usual, instead of letter-press. Sturz's method was to mix with printer's weak burnt oil a certain quantity of gold or silver bronze to the same consistency as that of strong copper-plate ink, and filling the plate with it to dab it in with the fingers. The plate being then nicely cleaned off, first with a rag dipped in a very weak solution of pearlash, and then with the palm of the hand in the usual way, was passed with very strong pressure through the press, and the impression when dry was polished by passing it through the press several times with the printed face against a highly polished steel plate, by which a beautiful brightness was imparted to the bronze. The copper-plate printers, however, adopt the less expensive method of first printing with a coloured ink ground with gold size and oil, and then rubbing the bronze on the paper just after it is printed.

M. De La Rue's instructions for producing good results by letter-press printing are as follows:—"Take the best printer's varnish, grind it to a thick consistency with the best burnt sienna or brown umber, and reduce this with De La Rue's gold size until it be of the thickness of thin treacle; ink the form in the usual manner, and when printed apply the bronze by rubbing it gently over the article with cotton wool. If leaf gold or leaf metal is required it must be laid on carefully, and when dry the sheets should be wiped to clear them of the superfluous bronze or metal. The gold printing is much improved by its being passed over polished steel plates, between powerful rollers." Dutch gold cannot be used in this style of printing.

Section VIII.—Copper-plate and lithographic printing.—Numbering machine.

Copper-plate printing is performed at what is called a *rolling press*. It consists of two parts, the *body* and the *carriage*. The body is formed of 2 cheeks of wood or iron placed vertically on a stand or foot which supports the whole machine. From this foot proceed 4 other vertical pieces joined by horizontal pieces supporting a strong even plank of wood or *table*, about 4½ feet long, 2½ feet broad, and about 1½ inch thick: within the cheeks are 2 rollers, the upper of iron, the lower of wood. These rollers run in the cheeks or gudgeons, formed by turning down the ends of the rollers on 2 pieces of wood in the form of half moons, lined with polished iron to assist their motion. One of the gudgeons of the upper roller carries a cross consisting of two or more levers crossing each other at right angles, by means of which motion is given to the upper roller. In old presses the space in the half moons left vacant by the gudgeons is filled with paper, pasteboard, &c., in order that they may be raised or lowered so as only to leave between them the space required for the carriage with the plate paper and blankets; but this adjustment is now usually performed with a screw.

In the process of printing, the plate is raised to the temperature of about 180°, by being placed on a grate over a charcoal fire, or by the more preferable mode now in use, on an iron box in which steam circulates. This gets rid of the noxious fumes arising from the burning charcoal, which formerly rendered copper-plate printing so injurious to health. The man takes up a small quantity of ink on a rubber made of linen rags strongly bound about each other, and dabs it over the face of the heated plate. He next removes the plate from the source of heat, takes off some of the superfluous ink with a piece of canvas, then with the palm of the left hand, next with that of the right, and to dry the hand and accelerate the wiping he dabs his hand from time to time upon a surface of whitening. The chief art of the printer consists in properly wiping his plate, and he must manage so as to remove every particle of ink or dirt from the

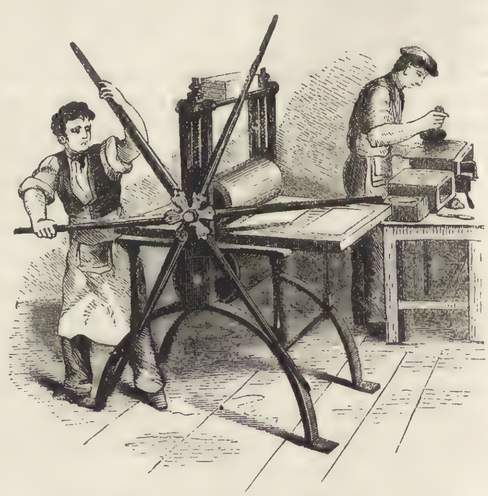


Fig. 1760. COPPER-PLATE PRINTING.

smooth surface, and yet not disturb the ink in the engraved parts. The plate is now deposited on the plank of the press, and over the plate is laid the damped paper which is to receive the impression, and over the paper are placed 2 or 3 folds of flannel or blanket. The arms of the cross are next pulled, and the plate with its furniture are thus passed between the rollers, which by their strong but equable pressure, force the moistened paper into the strokes of the engraving, by which it absorbs the ink and retains the impression. Some works require to be passed a second time through the press, as where the lines are deep and a black impression is desired.

The ink is composed of *Frankfort black*, which consists of the carbon of peach and apricot stones, with that of the bones of sheep or ivory produced by well

burning: this is ground with well-boiled nut oil on a marble slab. Three kinds of ink are usually employed, the *thin*, the *thick* and the *strong;* they differ only in their degrees of cohesion: the strong is used for the finer works. The stronger the ink the stronger must be the pressure, and as this requires more labour than a lighter pressure, the printer of course prefers a thin ink.

Some years ago Mr. Perkins contrived an improved copper-plate press, in which a tympan was introduced in order to save the expense of making the plates or blocks any larger than is necessary to receive the engraving. There are also other variations from the common form, which we cannot detail for want of space.

The *lithographic press* resembles the copper-plate press in several particulars, but differs from it by the pressure being accompanied by a sort of scraping movement. The first lithographic press consisted of a hollow table for holding the stone; this was inked by means of rollers, and the paper being laid on it, a tympan was brought down and a bar of wood pressed firmly upon it: the stone was then by the action of levers made to traverse from side to side beneath this bar. In the improved press (Taylor & Martineau's) there are two iron uprights rising from the bed or table, and the stone is supported by a carriage moving on rollers along a small railway. The scraper or bar, instead of being pressed down by a lever, is acted on by a spring which keeps it in close contact with the tympan. A cylinder worked by a handle sets the carriage in motion, and the stone is thus brought under the action of the scraper or pressing bar. The necessary adjustments are made by means of regulating screws.

An ingenious machine was invented by Mr. Bramah for numbering bank notes. The notes are printed from engraved steel plates, two notes on each plate, by means of roller presses worked by steam: the date and the signature are next printed in a different kind of ink, by means of a small cylindrical printing machine; the numbers are lastly added in a third kind of ink, by means of a numbering machine. Another machine, invented by Mr. Oldham, is now in use, which our space will not allow us to describe;[1] but the principle of it will be understood from the following brief notice of Mr. Bramah's invention. The number on each note is printed twice, first over the words *I Promise,* and again over the word *Bearer.* Any number being thus printed, the unit figure changes to the next in order, then again to the next, and so on until the change is required in the ten's place: the tens in like manner change in due order until we come to the hundreds, and these change as required, and so on. Taking the machine in its simplest form, as for a single note, it consists of a solid base of mahogany, to which the sides of the machine are firmly attached. These are of iron and only one is seen in the figure. From one side to the other of the machine are 3 axes, a a' a^2, to the last of which is attached the handle H, which is raised and depressed by the operator: to this handle is attached the platten or tympan T. When the handle is raised this plate may be opened, and the note to be numbered is introduced and placed in its

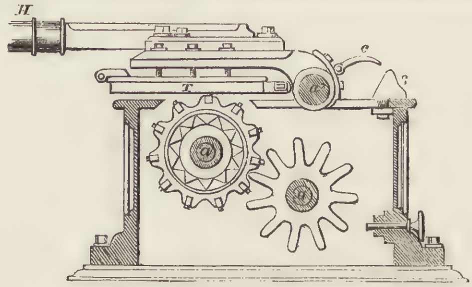


Fig. 1761.

proper situation by means of 2 guide pins; the plate is then shut and the note properly confined, there being 2 holes in the plate to allow the types containing the numbers to come in contact with the paper. On the axis a' are 5 brass circles of which only one is seen in the figure: each of these has 11 teeth, in which are cut notches to carry the digits 0, 1, 2 3 . . . . 9, and one blank: the other wheel on the axis a has also 11 teeth, so that moving one tooth on the latter turns the other one tooth round. There are 3 wheels on the axis, 2 of which are in contact each with one of the brass wheels on the 2 ends of the axis a^2, and the other is a central one by which the motion is communicated. When the handle H is raised nearly perpendicularly and stopped by the fixed stud *s* coming in contact with the back of the handle, the tooth or claw will have passed the upper tooth of the wheel a, which it does without resistance as it moves freely on its joint; but in returning the handle to its horizontal position, the claw having no motion in the opposite direction, catches the upper tooth and forces it round the interval of one tooth, and this again forces the wheel a' also one tooth, and consequently changes the number one place, as from 0 to 1, or from 1 to 2, &c., the several types being arranged in order round the wheel. Of the 5 circles on the axis a' suppose the 4 right-hand ones to have their blank teeth all up, and that the tooth 1 is upon the right-hand wheel, and suppose the impression No. 1 made at the two ends or sides of the notes by the two outside wheels, and that the wheel a is in contact with these two outermost circles. Then the handle being thrown back, the note removed, and another introduced, the claw *c* will have passed the upper tooth of the wheel a, and on returning it will catch and press forward this wheel one tooth, and this again the wheel on a', bringing the digit 2 to the upper position; the impression being made the same process if repeated will bring up No. 3, then No. 4, and so on to No. 9. Having run through the units it is necessary to bring up No. 1 on the wheel into the ten's place, which is done by making 2 strokes with the handle without printing; the axle a is now pushed on end by a

(1) This machine is a great improvement on Mr. Bramah's. A machine patented in March 1845 by Mr. Shaw, is fully described in the *Repertory of Patent Inventions:* it is in great request as a *paging machine*

proper nut so as to bring the wheel *a* in contact with the next brass circle; then, the blank being already up, the next stroke brings up the 0, making with the standing digit 1 No. 10; the next stroke gives 11, then 12, 13 . . . . . 19. The first wheel is now moved on by hand until 2 is the uppermost type; then similar steps being followed the Nos. 20, 21, &c., are obtained and lastly 99; when the first wheel becomes the place of hundreds, the second of tens and the wheel *a* is again put on end to engage the third type wheel, and so on to any extent up to 99,999, which is of course the highest number attainable by 5 type wheels. The operator in using the machine first inks the types with a small printer's ball.

Section IX.—Printing for the Blind.

The attainments made by certain blind persons prove that few intellectual pursuits are denied to them; a long list of poets, musicians, literary men, and mathematicians might be given in illustration of the degree of eminence which has been attained by this class of persons; yet notwithstanding the evidence thus afforded that their condition is no insurmountable obstacle to the acquisition of knowledge, there has been no general and systematic effort to raise the intellectual standard of the blind.

One of the earliest and most important measures for the instruction of the blind was the contrivance of characters in relief, over which a sightless person might pass his hands, and so ascertain by the form and arrangement of the letters, the sense they were intended to convey. These characters were first made in metal and in wood; they were frequently movable, and resembled in form the Illyrian or Sclavonian alphabet, it being thought that the square form of such letters would make them easily obvious to the touch. Large cushions on which characters were figured with inverted needles were also brought into use for the blind. But the discovery of embossed typography, which was made in 1784 by M. Valentine Haüy of Paris, soon banished all former methods, and allowed the blind to have the privilege of printing books for themselves, and of reading them when printed. The value of this invention would be immense if anything like uniformity of system could be insured, but unfortunately, almost every institution for the reception and education of blind persons, has it own distinct modes of teaching, and in many instances its own distinct alphabetical characters, so that the pupil, be he ever so well taught in one institution, is in a great measure isolated from the pupils in other institutions; and what is still worse, he is shut out from their printed books, many of which may not exist in the character with which he is alone conversant.

The greatest kindness which could possibly be shown to the blind, as it respects their intellectual progress, would be for those inventors and heads of institutions who are now pursuing separate and independent paths, to meet together and consult on a common alphabet, and a universal system of typography which should be adopted at all their establishments, so that the printing-press of one establishment should be a source of instruction not to the few who use the same character, but to all who speak the same language. Such a consultation, however, would only be so far valuable, as it faithfully represented the feelings and wants of the blind themselves. The best character to be adopted, is not that which is the most popular with the seeing public, or that which may be the least troublesome to the teachers in the several institutions, but that which *the blind can understand the most readily by means of their fingers*. An intelligent observer of the proceedings in *L' Institution Nationale des Jeunes Aveugles*, in Paris, remarks, "In England the blind are, I believe, required *by touch* to read symbols intended for the *eyes*, and which, because they are perfectly well adapted for one sense, have not very logically been deemed equally valid for another, the two not having together an idea in common. For instance, to the eye gifted with the power of looking over, almost at a glance, a territory of many miles extent, it is but little trouble to observe the difference between the diphthongs œ and æ, or between long-tailed and short-tailed letters of equally complicated forms. To the touch, however, which is stone-blind, the operation is difficult, tedious, and after all, unnecessary." [1]

The method adopted at the above-named institution will be explained in due course, but we will first give a brief notice of the invention and successive improvements and variations of printing in relief. The first idea of employing the fingers of the blind in reading written language is said to have been suggested to M. Haüy, by observing that a celebrated blind pianist, Mademoiselle Parodis, who visited Paris in 1784, distinguished the keys of her instrument by the touch, and also understood, by the same means, some maps in relief which had been then recently invented. The happy idea of printing written characters in relief, simple, and yet of vast importance, then occurred to M. Haüy, and he was fortunately gifted with a degree of zeal and enthusiasm which carried him successfully to the attainment of his object. After numerous experiments with different letters, to ascertain which appeared the most readily to be understood by the pupils, he fixed on a character nearly approaching the ordinary Roman, or rather inclining to the *italic*, and used letters from the upper and lower case in the ordinary manner, the capitals taking more of the *script* form than the small letters. He then commenced teaching gratuitously a number of blind children of the Philanthropic Society: his proceedings and experiments having been favourably reported on by a committee of the Academy of Sciences. He also wrote several works on the subject, the most celebrated of which [2] was translated into English by Dr. Blacklock, the blind poet, and

(1) Sir F. Head's *Faggot of French Sticks.*

(2) " Exposé de différents moyens vérifiés par l'expérience pour les mettre en état de lire à l'aide du tact, d'imprimer des livres dans lesquels ils puissent prendre des connaissances de langues, d'histoire, de géographie, de musique, etc.; d'exécuter différents travaux relatifs aux métiers."—Imprimé par les Enfants Aveugles. Paris, 1786.

published with his poems in London, 1793. An examination of twenty-four of Haüy's pupils before the royal family at Versailles in 1786, brought credit and fame to the teacher and his system, but he seems to have erred in commencing his printing, &c. on too large and expensive a scale, so that when inconveniences were perceived in the first form of characters used, it was not easy to abandon the defective alphabet on account of the bulky and costly works which existed in that character. The want of power to remedy errors, together with some want of judgment in his capacity of Director of the "*Institution Royale des Jeunes Aveugles*," (such was the title of his establishment,) gradually brought Haüy into disrepute, and after some years he retired on a pension, and his place was supplied by Dr. Guillié, an active enterprising man, who revived the printing, modified the letters, and published a number of elementary works for the instruction of the blind. The idea of an elementary volume, among the seeing public, is naturally that of an inexpensive, and generally a small and portable work; but these elementary volumes for the blind, on account of the great space occupied by the embossed letters, were ponderous folios published at 50 francs per volume. For a long time these constituted almost the only literature for the blind, not only in France, but in other countries. They included Greek, Latin, English, Italian, and Spanish grammars, extracts from poetical and prose writers, religious manuals, &c. Besides these works, Guillié published, in 1819, an historical notice of the mode of instructing blind children, all in embossed typography: this, as well as the foregoing, was however open to many of the same objections as Haüy's first books, the characters not being strongly enough marked to be read without much difficulty. Strangely enough, Haüy's name is not mentioned in this so-called historical notice. Previous to his retirement, M. Haüy had been invited to introduce his system in Berlin and St. Petersburg, which he did, in 1806, with advantage no doubt to the blind in those capitals, but with little pecuniary benefit to himself. The amount of embossed printing in Germany is however very small.

The difficulty experienced by the blind in reading the alphabets invented by the sighted, appears to have stimulated an ingenious blind person, named Louis Braille, to devise a system better adapted to the wants of his brethren. It is only necessary to close the eyes, and pass the fingers lightly over his alphabet, to be convinced that the system of *points* or *dots*, which he has chosen to indicate the different letters, is readily appreciated by the touch. To form the letters of the alphabet he makes use of only six points, disposed in a variety of ways. Of these he uses one point for letter *a*, two for letter *b*, and so on, but arranged with reference to a certain size of letter represented by a parallelogram of three dots by two ⠿, and shown in our diagram Fig. 1762, by the boundary lines of the perforations in the brass guide. It will be understood that the small circles represent raised dots forming each letter of his alphabet.

This system has one grand advantage connected with it, namely, that the blind are able to write freely and rapidly by puncturing the letters on paper

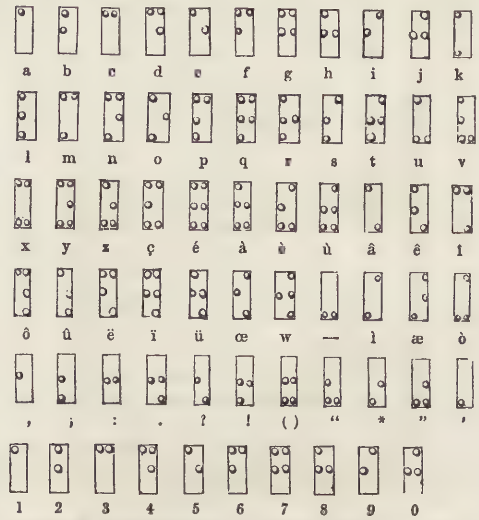


Fig. 1762. PUNCTURED ALPHABET, FOR THE BLIND, BY LOUIS BRAILLE.

with a style, and then (still better) to read their own writing, by turning the paper and passing their fingers over the burs which the style has raised.

Mr. John Bird, a blind gentleman and member of the medical profession,[1] who visited the continent last summer, for the purpose of inspecting the various institutions for the instruction of the blind, has kindly permitted us to copy a writing-frame in his possession, similar to those in use in three institutions of France and in one of Brussels, where Braille's arbitrary type is adopted to the exclusion of all others. By means of such writing apparatus each pupil, during his residence in the institution, writes a number of books, which he carries with him on leaving. In this way he multiplies copies of valuable works, and impresses deeply on his memory their various contents. In fact, his writing is a kind of printing, and in this sense we notice it. The writing-frame before us is, we suppose, one of the more elegant forms employed. It consists of three pieces, —*first*, a thin slab of highly-polished mahogany, thirteen inches long by nine and a half inches broad, on which is fixed a plate of zinc z, Fig. 1763, closely and sharply grooved; *secondly*, a double mahogany folding frame, united by hinges *h h*, between which the paper P is to be inserted; the under part of this frame fits over the metal plate, and is flush with it, while the upper part is furnished with fifteen holes on each side of its length, for receiving, *thirdly*, a brass guide *b b*, which, after the insertion of the writing-paper in the frame, is placed across the page, a brass peg at each extremity fitting into the corresponding hole in the mahogany frame. The brass guide has two rows of open spaces, and each space

(1) Ere long Mr. Bird will probably give to the world the fruits of his experience and the result of his travels in a comprehensive work on the condition of the Blind.

allows of the formation of one of Braille's letters within it. There are three dozen of these spaces in one line, so that the writer accomplishes two lines containing six dozen letters by puncturing the requisite number of dots within each space. This being done, he moves the brass guide one peg lower down, and

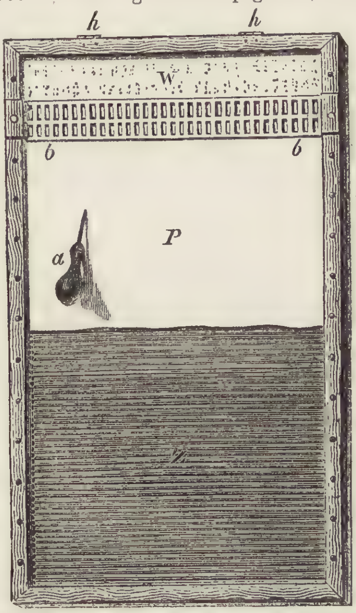


Fig. 1763. BRAILLE'S WRITING-FRAME FOR THE BLIND.

repeats the operation. In one page of the size of the writing-frame, he has thus the power of forming, without any assistance from others, 30 lines of writing, composed of 1080 letters, all perfectly legible to himself by turning the page. The style *a*, by means of which this is accomplished, is a rather blunt steel point, fixed in a small handle of ebony. The grooves in the zinc plate guide the writer in puncturing the dots in one or more of the positions 1, 2, 3, 4, 5, 6, Fig. 1764, according to the arbitrary arrangement of each letter. The blind, in making use of this frame, write, not as we do, from left to right, but like the orientals, from right to left. On reversing the paper, it is evident that they must read what they have written in the same direction as the sighted. An educated blind person with this writing-frame, and a good supply of paper in sheets of the proper size, may be to a great extent independent of the world; for he has the means of putting down his own experiences, or of recording the experience of others, in a form legible to himself and

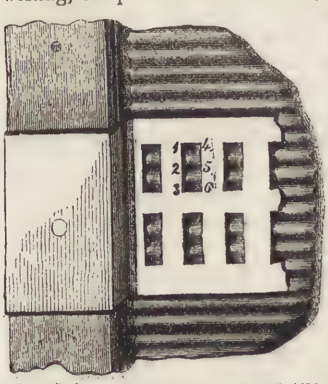


Fig. 1764. PORTION OF THE FRAME AND BRASS GUIDE, OF THE ACTUAL SIZE.

to all who have made themselves masters of the system. He has also the power of copying any work printed in embossed typography. Mr. Bird informs us, that when the intelligent blind of Paris, or the blind professors (ten in number), wish to possess a work of repute which has not yet been printed in raised characters, they engage M. Victor, an eminent sighted assistant, to copy the work on thin plates of brass, the indentions of which are afterwards filled with cement, which gives sufficient strength and consistency to the points to allow of as many as 100 copies being struck off by a press from this stereotyped page. In Sir Francis Head's work is a striking, though too ludicrous account of the method of writing which we have been describing;—" Not only are M. Braille's embossed symbols evidently better adapted to the *touch* than the letters and figures which have been so cleverly invented for the *eye-sight*, but to the blind they possess an additional superiority of inestimable value, namely, that they, the blind, can not only read this type, but with the greatest possible ease *make it*, and as I witnessed this very interesting operation, I will endeavour briefly to describe it. A blind boy was required to write down before me, from the dictation of his blind professor, a long sentence. With a common awl, not only kept in line, but within narrow limits, by a brass groove which the writer had the power to lower at the termination of each line, the little fellow very rapidly poked holes tallying with the letters he wished to represent. There was no twisting of his head sideways, no contortion of face, no lifting up of his right heel, no screwing up of his mouth, no turning his tongue from beneath the nose towards one ear, and then towards the other, in sympathy with the tails of crooked letters, which in great pain and difficulty, in ordinary writing, the schoolboy may be seen successively endeavouring to transcribe. On the contrary, as the little fellow punched his holes, he sat as upright as a cobbler hammering at the sole of a shoe. On the completion of the last letter he threw down his awl, and then like a young author proudly correcting his press, with his fore-finger, instead of his eyes,—which, poor fellow, looked like a pair of plover's eggs boiled hard,—he touched in succession every letter, and all proving to be correct, he stretched out his little hand and delivered to me his paper. To test the practical utility of the operation, a blind boy was sent for from another room. The embossed paper (for what was a hole on one side was, of course, a little mountain on the other) was put into his hands, and exactly as fast as his finger could pass over the protuberances made by his comrade, he read aloud the awled sentence which I had heard dictated. I may observe, that besides letters and figures, notes of music are also done by the awl."

Another ingenious blind Frenchman, M. Foucault, has done much to facilitate the progress of the blind. Among other inventions, he has produced the *Printing Key-Frame*, a somewhat costly apparatus, sold at 800 francs, but which affords the means of printing off, with considerable rapidity, whatever the blind

person wishes to convey to paper. It does not enable him to read what he has written; but M. Foucault has invented reproducing machines, by which sentences may be copied in raised typography. The Printing Key-Frame was exhibited in Paris, at the *Exposition* of 1849, and was rewarded with a gold medal and a favourable mention in the Report of the Central Jury. "The blind," says the Report, "who make use of M. Foucault's invention are placed in more favourable circumstances than the clearsighted. They are enabled to write without having ever learned how to form a single letter. It suffices to know how to read by the touch, to be capable of expressing their ideas in an eminently legible manner, inasmuch as they are shaped in typographic characters. The following is the process employed to obtain this curious result. All the letters of the alphabet, executed in relief and of considerable dimensions, are fixed on the upper extremity of metallic rods, made to slide longitudinally in proper contiguous canals. They are placed on the same plane, and in the form of a fan; each of them exhibits in its lower part the same letter as on the upper part, but of small size. It is a printing character; and the mechanism is so disposed that all the letters converge towards the same point, and on being successively pressed by the fingers, deliver their impressions successively on the same spot. Meanwhile, the paper changes its place in a certain fixed proportion with the motion of the letters, and thus the printing is delivered clean, well arranged, and well spaced. On the termination of a line the paper changes place in a direction perpendicular to the former, and the operation is renewed." The operation of this Printing Key-Frame was witnessed by thousands in the Great Exhibition in Hyde Park, where it also gained a prize medal. The inventor, M. Foucault, was himself the exhibitor, and formed an interesting specimen of talent, perseverance, and ingenuity, under the most discouraging circumstances. M. Foucault is a pensioner at the *Quinze Vingt*, an establishment for the blind in Paris; but by exerting his musical talents, and by keeping a small shop, in which he is assisted by his wife, he has earned the means of pursuing, at his own expense, those experiments and inventions by which he so zealously endeavours to benefit the blind. During nearly the whole of his three months' stay in England, at the time of the Great Exhibition, he was bearing his own expenses, and diligently working away with his Printing Frame, and explaining its use and mode of working to little groups of persons in the Crystal Palace, who gathered round him, often without any knowledge of the language in which he so eloquently addressed them, but from curiosity to see a blind person using with much rapidity this novel kind of printing machine.

In 1826 Mr. James Gall, of Edinburgh, began to study the various methods of teaching the blind, and to make experiments, with various arbitrary and Roman alphabets, in order that he might discover one sufficiently simple for finger-reading. In September 1827 he published the first book printed for the blind in the English language.[1] It consisted of only nine pages, four of which were embossed in high relief from wooden type. Mr. Gall next issued sheets printed from metal type, and found that they were easily read by the pupils of the Blind asylum. When he had perfected his alphabet to his own satisfaction, which was not until the year 1829, he commenced printing the Gospel by St. John. For this work he tried three different founts of type, the *double-English*, the *double-pica*, and the *great-primer*, printing and cancelling many sheets in each. The printing was finished in 1832, but the work was not published until 1834, when it appeared as a 4to volume, the price being at first, to subscribers, 1*l.* 1*s.*, though it subsequently sold for 6*s.* The shape of Gall's alphabet is given below, and although experience abundantly proved that its angular character made it exceedingly easy to the

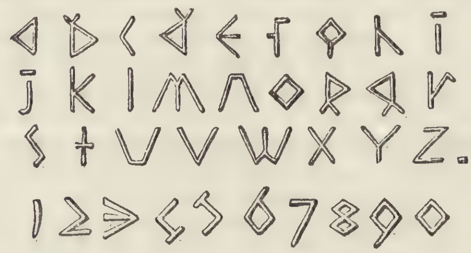


Fig. 1765. GALL'S ALPHABET AND NUMERALS FOR THE BLIND.

pupils, yet there is no doubt but that his system would have gained in general popularity, if he had from the first conformed it (as he afterwards felt bound to do) more nearly to our common alphabet. His mode of printing in relief was superior to all that had been previously done, being clear, sharp, and permanent; and in many parts of his system there were great improvements on Haüy's method, and added facilities for the learner. Gall is therefore justly regarded as the founder of the English school for the blind. On the first introduction of relief printing in England, it was thought that the fingers of the learners, in constantly passing over the embossed letters, would soon level the uneven surfaces. But Gall declares that his relief letters may be rubbed upon a hard table with the fingers for any length of time, and with any degree of pressure and speed, without the slightest deterioration; or they may be violently beaten on a board with the fleshy part of the closed fist, and the relief will remain as perfect, and will stand out as prominently as ever. Mr. Gall successively published the Epistle to the Ephesians, that to the Philippians, the Gospel by St. Luke (printed for the British and Foreign Bible Society, London,1838,) the Acts of the Apostles, and a series of Tracts for the Blind, price 6*d.* each, printed for the Religious Tract Society. In most of those works he adopted a modification of his alphabet, bringing it into greater resemblance to the common alphabet, but using a rough

(1) "A First Book for teaching the Art of Reading to the Blind; with a short statement of the principles of the art of printing as here applied to the sense of touch." Edinburgh. Published by James Gall.

or serrated character, which instead of being a help to the blind was positively a hindrance to the reading of his works.

Intelligent and benevolent efforts to benefit the blind were soon made in different parts of England, but the question of the alphabet still remained a stumbling-block. Various arbitrary methods were invented, and the Society of Arts of Edinburgh gave rise to no less than 19 new alphabets by its offer of a gold medal value 20*l.* for the best communication on a method of printing for the blind. Among the various English alphabets for the use of the blind, there is one of an ingenious kind invented by Mr. Lucas, whose system, however, partakes too much of the nature of short-hand. It has been adopted and improved upon by the "London Society for teaching the Blind to Read," and is one of the most popular of the arbitrary systems. There is also an alphabet by Mr. W. Moon, master of the Blind Asylum at Brighton, in which the common alphabet is taken as the foundation, but is greatly simplified. This is a very recent and meritorious effort to improve the teaching of the blind. But there is yet another alphabet, which is constructed on the same principle, and bears a considerable resemblance to that of Louis Braille; whether suggested by it, or an independent invention, we are not informed. It is the "New Embossed Alphabet for the Blind," of Mr. G. A. Hughes, himself blind, and conducting an institution for the instruction of the blind in the Westminster Bridge Road, London. Several machines were sent to the Great Exhibition by Mr. Hughes—1. To enable persons born blind to write in raised characters without type. 2. To enable the blind to write in skeleton Roman capitals, which can be read by themselves as well as by those gifted with sight. 3. To facilitate the casting of accounts, and making general arithmetical calculations by tangible characters. 4. A machine to copy and emboss music on paper. Mr. William Hughes, governor of the Blind Asylum of Manchester, also exhibited a typographical or writing machine for the blind, which was favourably noticed in the Jury Report as being the most simple in its operation of any in the Exhibition. It is a remarkable circumstance, that the simple and highly useful Writing Frame of Louis Braille should have been either absent from or overlooked in our Exhibition, considering that its invention dates twelve years ago, and that its merits are so well known in Paris. We have searched the Catalogue and Jury Report in vain to find some mention of it.

Time and experience can alone decide between the claims of all these contending systems; but we shall never make real progress until we give due precedence to the inventions and suggestions of the educated blind themselves. They are the only persons really qualified to decide as to what is the best and easiest mode of instruction, and their judgment should be received with all deference by those who can never gain their experience without the endurance of their calamity.

While many difficulties have interfered with the progress of the various institutions for the blind in this country, better success has attended the proceedings at Boston in the United States. This case is thus described in the Jury Report:—"In 1833, the Perkins Institution for the Blind was established at Boston, and Dr. S. G. Howe, a gentleman distinguished through a long series of years for his philanthropic labours, was placed at its head. As Gall had done, Dr. Howe took Haüy's invention as the basis of his system, and soon made those improvements and modifications which have rendered the Boston press so famous. He adopted the common Roman letter of the lower-case. His first aim was to compress the letter into a comparatively compact and cheap form. This he accomplished by cutting off all the flourishes and points about the letters, and reducing them to the minimum size and elevation which could be distinguished by the generality of the blind. He so managed the letters that they occupied but a little more than one space and a half instead of three. A few of the circular letters were modified into angular shapes, yet preserving the original forms sufficiently to be read by all. So great was the reduction that the entire New Testament, which, according to Haüy's type, would have filled 9 volumes and cost 20*l.*, could be printed in 2 volumes for 16*s.* Early in the summer of 1834 he published the Acts of the Apostles. Indeed, such rapid progress did he make in his enterprise, that by the end of 1835 he printed in relief the whole of the New Testament for the first time in any language, in 4 handsome small 4to. volumes, comprising 624 pages, for 4 dollars. These were published all together in 1836. The alphabet, thus contrived by Dr. Howe in 1833, it appears, has never since been changed. It was immediately adopted, and subsequently became extensively and almost exclusively used by the seven principal institutions throughout the country. It is now the only system taught or tolerated in the United States, and requires only to be better known in Great Britain and elsewhere to be appreciated. In America seventeen of the States have made provision for the education of the blind, and as universal education is the policy of the country, as well as its proudest boast, these books for the blind soon became in great demand. Dr. Howe, some time since, proposed a library for the blind, and with a view of increasing the number of books as rapidly as possible, arrangements have been made between the several institutions and presses to exchange books with each other, and not to print any work already belonging to the library for the blind."

Similar care bestowed on the several institutions of this country by some powerful and influential mind, and a similar disposition among the managers of the different establishments to establish harmony of action, would be of immense advantage to the blind. Almost simultaneously with the Boston institution, another was founded in Philadelphia. It appears that their presses and systems of typography were established without being apprised of the efforts of each other, consequently there were diversities in the plan which will probably disappear as time goes on. The Philadelphia

press produced portions of the New Testament, and several religious and other works, but it has now ceased to act; and, when revived, it is more than probable that it will act in complete conformity with the Bóston press, so that there may be entire unanimity in American institutions for the blind.

Printing for the blind has been carried on extensively in Glasgow, the character used being the common Roman letter deprived of the small strokes at the extremities. The main difference between the Glasgow and Boston alphabets is, that one is in the upper and the other in the lower case. This difference is not sufficient to prevent an interchange of books, which has been carried on to the advantage of both parties. Mr. Alston of Glasgow was the first to print the whole Bible for the blind, which he did in 19 volumes. Since his death in 1846, the Glasgow press has been comparatively inactive. Great Britain has many distinct systems of typography for the blind at the present day, and therefore many distinct sources of embarrassment to the unfortunate individuals who may be desirous of learning the art of finger-reading.

The Jury Report strongly urges the speedy adoption of one system throughout the country, giving a decided opinion in favour of Howe's typography; and it is the duty of all who wield the pen to represent the injustice done to the blind by the present divisions, and the imperative call to a more humane and unanimous course of action. Yet our own convictions incline to those systems which the blind themselves prefer, rather than to any, however popular, which are invented by the sighted. Therefore we would gladly see greater use made in this country of the plan invented by the blind G. A. Hughes, or that of the blind Louis Braille, which Sir F. Head, Mr. Bird, and others, have seen in such successful operation in Paris.

Section X.—Galvanoplastic and other Forms of Printing.

The Great Exhibition brought into notice some new forms of printing, some of which were of a remarkable character. The following notices of them are chiefly derived from the Jury Report:—

By means of a galvanoplastic process fossil fishes have been reproduced upon paper with the exactness of nature. Successive layers of gutta percha are applied to the stone containing the fish, and a mould is obtained, which being submitted to the action of a voltaic battery, is quickly covered with coatings of copper, forming a plate upon which all the markings of the fish are reproduced in relief, and which when printed at the typographic press give a result upon the paper identical with the object.

The Imperial Printing-office of Austria, which exhibited these results, also produced some remarkable effects of *galvanography*. A plate of silvered copper is covered by an artist with different coats of a paint composed of an oxide, such as that of iron, burnt terra sienna, or black-lead ground with linseed oil. The substance of these coats is thin or thick, according to the intensity of the lights and shades in the picture. The plate is then submitted to the action of the galvanic battery, from which another plate is obtained reproducing an intaglio copy with all the unevenness of the original painting. This is an actual copper-plate resembling an aquatint, and obtained without the assistance of the engraver.

The process of *galvanoglyphy*, invented in England, and patented by Mr. Palmer, is not less interesting. A drawing is etched upon a plate of zinc coated with varnish; and upon this a coat of ink is spread by means of a small composition roller. The ink is deposited only on those parts where the varnish has not been broken through by the etching-needle, the sunken portion of the engraving being left free. When the first layer is dry, a second is applied, then a third, and so on, until the original hollows are considered to be deep enough. The plate, thus prepared, is placed in the galvanic-battery, and another plate is thereby produced, on which all the hollows of the engraving are reproduced in relief. This relief is more or less raised according to the number and thickness of the coats of ink successively applied.

In order to obtain casts in relief from an engraving, the process of *chemitypy* may be adopted. A polished zinc plate is covered with an etching ground; the design is etched with a point, and bitten in with dilute aquafortis: the etching ground is then removed and the acid well cleaned off, by first washing the hollows of the engraving with olive-oil, then with water, and afterwards wiping clean. Filings of fusible metal are then placed on the plate, and the latter is heated by means of a spirit-lamp until the fusible metal has filled up all the engraving: when cold, the surface of the fusible metal is scraped down to the level of the zinc plate, leaving only that portion of it which entered the hollow parts of the engraving. The plate of zinc is next submitted to the action of a weak solution of muriatic acid; the zinc alone will be attacked, and the fusible metal which was in the hollows of the engraving is now left in relief, and may be printed from at the typographic press.

The process of *paneiconography*, invented by M. Gillot of Paris, has for its object the reproduction of any lithographic, autographic, or typographic proof, any drawing with crayon or stump, or any engraving upon wood or copper. This comprehensive object gives the name to the process from *πᾶσαν εἰκόνα γράφειν*, "to delineate all kinds of images." A plate of zinc is to be well polished with pumice-stone, and on this the artist executes the required design with lithographic crayon or ink, or the impressions from lithography, wood-engraving, or copper-plates, may be transferred to the zinc-plate, as in the process of *anastatic printing*.[1] The surface is then inked over

(1) *Anastatic printing* (from *ἀνίστασθαι, stand up,*) is performed as follows:—Immerse in, or moisten with, dilute nitric acid, the print or sheet of letter-press, &c. which is to be transferred; the acid softens the ink, and on passing the print in contact with the zinc-plate through a roller-press, the zinc-plate will take a reversed fac-simile of the print; and on passing an inked roller over the zinc-plate the ink will adhere only to the slightly-raised lines of the reversed impression, and on passing this with a sheet of white moistened paper through the press, a perfect fac-simile of the original print is produced.

with a roller so as to increase the thickness of the ink, which is afterwards consolidated by dusting finely-powdered rosin over the plate, by means of a pad of wadding: the rosin adheres only to the ink, and is readily removed from the other parts of the plate. Afterwards, in order to obtain a relief-block, the plate is placed on the bottom of a shallow trough, containing very dilute sulphuric or hydrochloric acid. By means of a rocking motion given to the box, which for that purpose is fastened to an axis, the acid is caused to pass slowly and continuously to and fro over the surface of the plate. After the lapse of half an hour, if it be a crayon drawing, the etching is completed, and a relief-block is obtained, in which it is only necessary to remove the large whites by saw-piercing. But should the plate contain written matter, or many very fine lines, it must be withdrawn from time to time, and the surface again inked with lithographic ink, and dusted with powdered rosin, so that the edges may be protected as much as possible from the undermining action of the acid: these operations must be repeated until the necessary depth is obtained. Transfers may be made from very old impressions of wood-engravings by sponging them several times at the back with acidulated water, and then operating as is usual with lithographic transfers.

PRISM. See LIGHT.

PRUSSIAN BLUE. This pigment was discovered in 1710, by Diesbach, a colour-maker at Berlin: the method of preparing it was first described by Woodward in the Philosophical Transactions for 1724. It is a compound of iron and cyanogen, and is known to the chemist as the *sesqui-ferrocyanide of iron.* It is prepared by precipitating solutions of peroxide of iron by means of *ferro-cyanide of potassium.* The first step, therefore, in the manufacture of Prussian blue, is the preparation of ferrocyanide of potassium, or *prussiate of potash*, as it is more commonly termed. For which purpose certain animal matters are employed, as sources of *cyanogen* (C_2 N or Cy. See CYANOGEN), such as chips of horns, hoofs, woollen rags, *greaves*, or the refuse of tallow-melters, consisting chiefly of cellular membrane, from which the fat has been expressed, dried blood, hair, skin, &c. These are triturated with potash, or pearlash, and then burnt or fused at a high temperature in an iron pot. The resulting mass, called *prussiate cake*, is a dark grey mass, which, on being lixiviated with hot water, yields what was formerly termed *lixivium sanguinis*, or *blood lye*: this, on being evaporated, yields lemon-coloured crystals of prussiate of potash. The first crop is very impure; it is re-dissolved, and the second crystallization is allowed to go on for a fortnight, without disturbing the contents of the coolers. In the formation of this salt, the essential ingredients are animal matter, rich in nitrogen and metallic iron, or its sulphuret. The iron is usually obtained at the expense of the pot in which the process is conducted, or iron filings are added in the charge. The sulphuret of iron is formed first by the decomposition of the sulphate of potash contained in the impure potash, or pearlash, employed. The presence of charcoal at a red heat converts the sulphate of potash into bi-sulphuret of potassium; and this is further decomposed by the iron with which the sulphur unites. It is important to exclude the air as much as possible, in order to prevent the oxidation and destruction of the cyanide of potassium as it is formed. On treating the mass with hot water, the cyanide of potassium is dissolved out; and this is quickly converted into ferrocyanide, by means of the oxide or sulphuret of iron.

Ferrocyanide of potassium (2K Cfy + 3HO, or 2K, C_6 N_3 Fe + 3HO) crystallizes in large transparent yellow crystals, derived from the octahedron with a square base. They readily cleave in a direction parallel to the base of the octahedron, and are tough and difficult to powder. They are soluble in 4 parts of cold, and in 2 of boiling water; but are insoluble in alcohol. They have a mild saline taste, and are permanent in the air. By exposure to a gentle heat, this salt loses its colour, parts with 3 equivalents of water, and becomes anhydrous. At a high temperature it yields cyanide of potassium, carburet of iron, and various gaseous products. If air be present, the cyanide of potassium becomes cyanate of potash.

This salt is an excellent re-agent for distinguishing the metals from each other. All the precipitates thrown down by this salt are double compounds of cyanide of iron with cyanide of the metal thrown down. The precipitate from sulphate of copper is of a fine brown colour, and has been used as a pigment; but, being somewhat transparent, it does not cover well. The precipitate from the peroxide salts of iron is of a very intense blue: this is *Prussian blue*, or, as it is named in some parts of the continent, *Paris blue.* There is some disagreement among chemists as to the exact composition of this precipitate. The fact is, that several *distinct* deep blue compounds are formed under different circumstances which have been regarded as identical. According to Berzelius, ordinary Prussian blue consists of C_{18} N_9 Fe_7 or 3 Cfy + 4Fe, and is best prepared by adding pernitrate of iron to a solution of prussiate of potash, the latter slightly in excess. A bulky and intensely blue precipitate is formed, which, on being washed and dried at a gentle heat, shrinks considerably. When dry, it is hard and brittle, and resembles the best indigo: the fresh fractured surface has a fine copper-red lustre. Prussian blue is insoluble in water and dilute acids, except oxalic acid, a solution of which dissolves it. Strong sulphuric acid converts it into a white pasty mass, which resumes its blue colour on the addition of water. The colour is instantly destroyed by alkalies, which dissolve out a ferrocyanide, and leave oxide of iron. The colour is also bleached by the direct rays of the sun, but it returns when the pigment is left in the dark. When heated in the air, Prussian blue burns like tinder, leaving a residue of peroxide of iron; but when heated in a close vessel, it disengages water, cyanide of ammonium, and carbonate of ammonia, and leaves carburet of iron. Prussian blue is a beautiful pigment, both as an oil

and water colour, but it is not very permanent. It is largely used in the decorative arts; also as a dye-stuff and in calico-printing. It is used for some of the varieties of *stone-blue*, for concealing the yellow colour of linen, and it is also used in starch. It is employed in certain writing-fluids, or blue inks, oxalic acid being the solvent. The Prussian-blue of commerce is very impure: it contains alumina, and other substances, which injure the brilliancy of the colour.

The Prussian-blue precipitate is thus formed from the solution of ferrocyanide of potassium, by means of a salt of iron containing no protoxide. If the iron be but partially peroxidized, the precipitate will at first be of a pale blue, which becomes a dark blue by exposure to the air. This pale blue precipitate consists of a mixture of prussiate of the protoxide and prussiate of the peroxide of iron. If exposed to air, in a moist state, it becomes of a beautiful dark blue colour; but this new combination, formed by the absorption of oxygen, is essentially different from that produced by the precipitation, by means of the peroxide of iron, since it contains an excess of peroxide, in addition to the usual 2 cyanides of iron: hence it is called *basic Prussian blue;* and, from the property of its being soluble in water, *soluble Prussian blue.*

In the manufacture of this pigment, on a large scale, the first process is the production of the prussiate of potash. For this purpose the raw materials require some previous preparation. If blood can be procured in sufficient abundance, it is to be preferred: it is evaporated to dryness, powdered and sifted. The other materials, such as parings of hoofs, horns, hides, woollen-rags, &c., are thoroughly dried and then used, or they are calcined in cast-iron cylinders. The latter plan allows the ammoniacal products to be collected, and to a certain extent prevents the escape of nauseous vapours, which cause this manufacture to be a nuisance to the whole neighbourhood. But on the other hand, it is stated that the prussiate is more easily produced when the animal substances are employed in the uncalcined state. 8 lbs. of horn or hoofs, and 10 lbs. of dry blood, yield about 1 lb. of charcoal. This is mixed with good pearlash, either dry or by soaking it in a strong solution of the alkali. The proportions are about 1 part of carbonate of

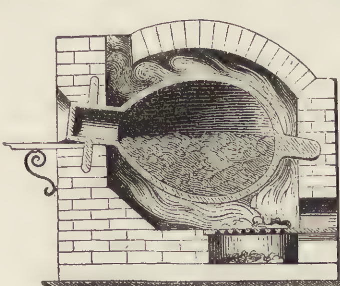


Fig. 1766.

potash, $1\frac{1}{2}$ or 2 of charcoal, or about 8 parts of hard uncarbonized animal matter. The calcining-pot, shown in section in the furnace, Fig. 1766, is oval in form, with a narrow neck, to allow the mouth to be closed with a small plate. It is of cast-iron, about 2 inches thick in the belly. It is built in the furnace in a sloping direction, and is supported on the back wall by a projecting knob, while it is steadied near the mouth by 2 arms built into the brick-work. The pot occupies the greater part of the furnace, in order that the flame may play closely upon it. The fireplace is situated behind, in order to prevent the workmen from being inconvenienced by the heat. A stone slab is placed before the mouth, to prevent loss of materials in discharging the pot. If fresh animal matter is used in the charge, the pot is left open at the mouth, in order to allow of the stirring of the contents with an iron scoop, and of the introduction of fresh materials, as the swelling subsides. In the course of 5 or 6 hours nauseous vapours cease to be evolved, the flame becomes smaller and brighter, and a smell of ammonia appears. At this stage no more fresh materials are added, but the heat is increased, and the mouth of the pot closed, or only opened every half-hour for the purpose of stirring up the charge with the iron rabble. When flame ceases to be given off from the mixture, the process is completed. When the animal matter has been previously carbonized, the pot is closed as soon as the charge is well ignited; and it is only opened for a few seconds every quarter of an hour, for the purpose of stirring. For some time a body of flame bursts out every time the cover is removed; but when this ceases, the mixture softens down into a paste. The flame gradually becomes less and less as before, and when it ceases the process is complete. The plan introduced at Glasgow, in 1824, by the late Charles Mackintosh, of agitating the fluxed mass by machinery in closed pots, has greatly increased the yield of prussiate from the same quantity of animal matter. When the charge consists of about 50 lbs. of charcoal, and the same weight of good pearlash, the operation lasts about 12 hours with a cold pot; but only 7 or 8 if a second charge be added as soon as the first is removed. The fused mass is removed with an iron scoop, and cooled in small portions as quickly as possible. It is next put into water, a moderate heat is applied, aad the solution is filtered through cloths. The charcoal left in the filter, mixed with fresh animal charcoal, is used in the next charge.

Most of the iron in the ferrocyanide is obtained from the pot in which the operation is conducted. When this wears into holes it is taken out, patched with iron cement, and built in again with the sound side undermost. If iron filings (about $\frac{1}{100}$ or $\frac{2}{100}$ by weight of the potash) be mixed with the charge, the corrosion of the pot is not so rapid.

The solution is not a pure ferrocyanide: a portion of the materials not having absorbed a sufficient proportion of iron, forms only cyanide of potassium; it is also contaminated with carbonate, sulphate, and phosphate of potash, phosphate of lime, &c., from the impure potash and the incinerated animal substances. Before evaporating the lye a solution of protosulphate of iron is added sufficient to re-dissolve the white precipitate of cyanide of iron, which first

falls, and so convert the cyanide of potassium which is present in the liquor, into ferrocyanide of potassium. The solution is evaporated and the crystals removed: the mother liquor is also evaporated, and yields a somewhat inferior ferrocyanide.

According to Dumas[1] the following results ought to be obtained from the calcination of 100 parts horn clippings and the addition of 40 parts of alkali to the resulting animal charcoal:—

100 parts horn clippings	Solution of carbonate of ammonia (15° B)	50	
	Oil	16	
	Animal Charcoal	30—30	46.80 of fused prussiate cake = 7.02 prussiate of potash.
	Alkali	40	

In order to precipitate the Prussian blue from the solution of prussiate of potash, green sulphate of iron is employed on account of its cheapness, although the red sulphate, nitrate or muriate of iron, affords a richer blue pigment. The salt of iron employed must be free from copper, or the precipitate will have a dirty brownish hue. "The green sulphate of iron," says Dr. Ure, "is the most advantageous precipitant, on account of its affording protoxide to convert into ferrocyanide any cyanide of potassium that may happen to be present in the uncrystallized lixivium. The carbonate of potash in the lixivium might be saturated with sulphuric acid before adding the solution of sulphate of iron; but it is more commonly done by adding a certain portion of alum, in which case alumina falls along with the prussian blue, and though it renders it somewhat paler, yet it proportionably increases its weight; whilst the acid of the alum saturates the carbonate of potash and prevents it throwing down iron-oxide to degrade by its brown-red tint the tone of the blue. For every pound of pearlash used in the calcination, from 2 to 3 lbs. of alum are employed in the precipitation. When a rich blue is wished for, the free alkali in the prussian lye may be partly saturated with sulphuric acid before adding the mingled solutions of copperas and alum. One part of the sulphate of iron is generally allowed for 15 or 20 parts of dried blood, and 2 or 3 of horn shavings or hoofs. But the proportions will depend very much upon the manipulations, which if skilfully conducted, will produce more of the cyanides of iron, and require more copperas to neutralize them. The mixed solutions of alum and copperas should be progressively added to the lye as long as they produce any precipitate. This is not at first a fine blue, but a greenish grey, in consequence of the admixture of some white cyanide of iron: it becomes gradually blue by the absorption of oxygen from the air, which is favoured by agitation of the liquor. Whenever the colour seems to be as beautiful as it is likely to become, the liquor is to be run off by a spigot or cock from the bottom of the precipitation vats, into flat cisterns to settle. The clear supernatant fluid, which is chiefly a solution of sulphate of potash, is then drawn off by a syphon; more water is run on with agitation to wash it, which after settling is drawn off again, and whenever the washings become tasteless the sediment is thrown upon filter sieves and exposed to dry, first in the air of a stove, but finally upon slabs of chalk or Paris plaster. But for several purposes, Prussian blue may be best employed in the fresh pasty state, as it then spreads more evenly over paper and other surfaces. A good article is known by the following tests: it feels light in the hand, adheres to the tongue, has a dark lively blue colour, and gives a smooth deep trace; it should not effervesce with acids, as when adulterated with chalk, nor become pasty with boiling water, as when adulterated with starch."[2]

By passing chlorine into a somewhat dilute and cold solution of ferrocyanide of potassium, the liquid acquires a deep reddish green colour, and no longer precipitates a salt of the peroxide of iron. By evaporation, prismatic or tabular crystals of a beautiful ruby red tint are produced: they are permanent in the air, and soluble in 4 parts of water, forming a dark greenish solution. This salt is named *red prussiate of potash,* or more properly *ferridcyanide of potassium* K_3, Cy_6 Fe_2, and is formed by the abstraction of an equivalent of potassium from 2 equivalents of the yellow salt. The red salt is used in calico-printing, and both salts are "employed in *de laine* printing as well as in dyeing wool; the blue from the red prussiate being found more durable when fixed by peroxide of tin. The red salt is also mixed with wood colours to oxidize them, or produce the great depth and beauty of colour which long expósure to air without light, otherwise induces in the dye woods."—*Jury Report,* Class II.

The colour known in commerce as *Turnbull's blue,* is the precipitate formed by adding a solution of ferridcyanide of potassium to a protosalt of iron: it is produced by the substitution of 3 atoms of iron for the 3 of potassium. Its colour is a little brighter than ordinary Prussian blue. It is prepared in the arts by adding to the protosulphate of iron a mixture of yellow prussiate of potash and hypochlorite of soda.

Patents have been taken out at various times for improved, or supposed improved, methods of manufacturing prussiate of potash. The following details of a patent taken out in January 1840, in the name of Mr. Berry, involve chemical details of great interest. The specification states that the common process entails the loss of a considerable quantity of nitrogen, either in the free state or under the form of carbonate of ammonia. To avoid this loss, the primary matters are treated differently, so as to collect the nitrogen which escapes during the distillation, and to cause it to enter into combination with carbon, iron, and potassium. Instead of collecting the carbonate of ammonia in or by an absorbent medium, it is made to pass through a quantity of charcoal, iron, and potash placed in

(1) Chimie Appliquée. See also Gmelin's Handbook of Chemistry, vol. vii. forming vol. i. of the Organic Chemistry. Cavendish Society's Translation, 1852.

(2) Dictionary of Arts, Manufactures, &c. Article PRUSSIAN BLUE. See also Dumas, Chimie Appliquée, tom 7e, pp. 652—662.

an iron tube and maintained at a red heat. The carbon on the one part decomposes the carbonate of ammonia and forms bicarburetted hydrogen, and at the same time gives up part of it to the nitrogen, which proceeds from the decomposed ammonia and thereby forms cyanogen, which in its turn combining with the reduced potash forms ferrocyanide of potassium or prussiate of potash. To obtain the most complete reaction, the ingredients which constitute the decomposing compound must be divided or reduced. This may be done by one of the following methods:—*First method.* Reduce the charcoal to fragments of about the size of a nut or walnut; then dissolve the potash (the carbonate or nitrate) in urine if a sufficient quantity can be readily obtained, otherwise in common water. The iron is to be rendered soluble by the addition of nitric or acetic acid. The solution of potash and nitre is next to be poured on the charcoal; the saline lye will soon be absorbed; next pour in the solution of iron, stir the mixture, and evaporate the water without calcining the compound. The compound, when dry, is to be again pulverised and introduced into iron tubes. The proportions which have been found to give good results in this process are, ordinary potash, 30 parts; saltpetre, 10; acetate, or nitrate of iron, 15; coke, or ordinary charcoal, 45 to 55; dried blood, 50. *Second method.* This consists in the substitution of a mechanical for a chemical division. The potash, nitre, and charcoal are introduced into a barrel with iron filings. Some cannon balls are to be put into the barrel, which, being made to revolve on an axis, the balls will grind the compound and reduce it to small fragments mixed together. The compound is either transferred to the cast-iron pipes, or kept for use in a dry place. The proportions which have been found to answer in this process are, 20 parts of ordinary potash; 10 of saltpetre; 20 of iron filings; 45 to 55 of coke or charcoal; 50 of dried blood. The compound ingredients prepared by either method are introduced, when perfectly dry, into a series of pipes connected together, and contained in a furnace similar to that used for heating the retorts in the manufacture of gas. [See Gas.] But instead of placing the pipes in a horizontal position, which renders it difficult to introduce and draw out the materials, they may be placed vertically, in which case the dry compound is not completely pulverised, but left in lumps in order to allow the gases to circulate more readily. The animal matter is placed in a separate compartment, and in a cast-iron retort connected with the vertical pipes. This retort is furnished with a safety-valve. The pipes must be raised to a red heat before the retort is heated, in order that, from the commencement of the operation, the decomposition of the gases may take place. The gas evolved by the decomposition is inflammable when issuing from the pipes, and the colour of the flame indicates the process of the operation. The colour differs generally but little from that of the heated cast-iron pipes in the furnace. When this colour approaches to pink, the reaction is almost complete, so that very little, if any, ammonia has escaped decomposition. When the jet of gas becomes smaller and clearer, and there is a good fire under the retort, the operation is nearly terminated; the animal matter is reduced into nitrogenated charcoal, which is commonly used for the manufacture of prussiate of potash, and which is still to be employed in the same manner and treated as usual. On the other hand, the nitrogen, ammonia, and other gases, by combining with the decomposing substances contained in the pipes, have been transformed into prussiate of potash. The charge must then be directly removed from the pipes, and being at a red heat, it should be at once thrown into water in order to extinguish it rapidly, the whole being well stirred and allowed to settle. The clear liquor is then to be drawn off, and this forms the strongest solution: warm water is then to be poured on the carbonaceous residuum, and being well stirred and allowed to settle, the liquid is drawn off. This operation is continued until the residuum is exhausted. The strong solutions are to be evaporated and crystallized, and the prussiate is extracted according to the old process. The solutions which will not crystallize contain carbonate of potash: this is extracted therefrom to be employed again. The same is done with reference to the residuum of charcoal and iron. All this residuum is carried to the following operation, to which is added the animal charcoal furnished by the first operation, by the calcination of animal matter. Besides this animal charcoal, a proper quantity of fresh charcoal is added in order to preserve, as far as possible, the same proportions in the decomposing mixture. After some operations, the animal charcoal may be found completely deprived of nitrogen: a portion of it is in such case laid aside, and a proper quantity of fresh animal charcoal substituted. Thus, after a short time, the coke or vegetable charcoal first employed, is completely set aside, the whole operation being effected by two kinds of animal charcoal, of which one is almost deprived of nitrogen, and the other contains a large quantity of the same.

The apparatus in which the above process is conducted consists of a furnace, of which a horizontal section is shown in Fig. 1768, constructed for the reception of 4 elliptical pipes, P, P^1, P^2, P^3. The

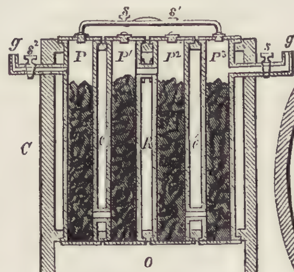


Fig. 1767.

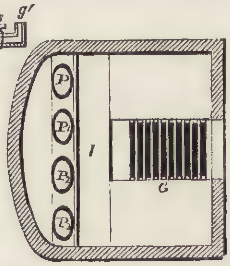


Fig. 1768.

furnace is so arched as to reverberate the heat and drive it back on the pipes. These pipes are placed on the focal plane of the ellipsoid, formed by the brickwork: G represents the grating of the furnace,

coal or coke being the fuel. R is the pot or retort: it is placed in a separate compartment, as seen in Fig. 1770. *c* is a connecting tube from the retort and the elliptical pipes P. In Fig. 1769 the shape of this tube *c* will be better seen: also its cocks $s\,s'$, and

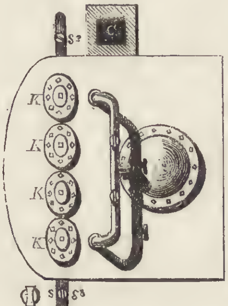


Fig. 1769.

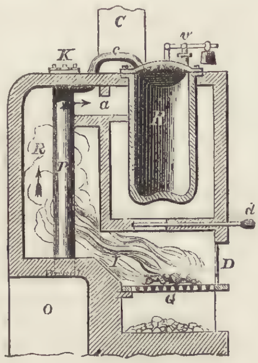


Fig. 1770.

its connexion with the pipes P, P^1, &c.: *v* is a safety-valve, *c* the cover of the pot or retort R, and D the door of the furnace. O is an open space or shed roofed over, and under it the pipes are emptied. The arrows indicate the direction of the current of heat: it traverses the intervals between the pipes, and ascends behind them, passing through the aperture *a* in the brickwork, which may be closed by a damper. The heat passes through this aperture and strikes against the sides of the pot when the valve is open. Another damper *d* must also be open to expose the retort to the direct action of the fire. The smoke escapes by a lateral passage into a chimney C. There is a direct communication between the chimney and that compartment of the furnace which contains the pipes, so that the heat reflected from the part R, strikes on the pot or retort only when the pipes are sufficiently heated. In Fig. 1770 is shown an inclined plane I, shown also in Fig. 1768, also the junction tubes which connect the 4 pipes with their gas-burners g, g^1 and the cocks s, s^2. *k k* are covers closing the pipes, and having holes formed in them which are closed by the stoppers *p p*. Whether the pipes be placed vertically or horizontally, it is desirable to be able to change the direction of the current of gas, which is done by closing for one hour (if the operation is to last for two hours) the cocks $s^1\,s$, and opening $s\,s^2$, in which case the gas passes through *s* into the left-hand branch *c c c c*, and entering P passes through the channel at the bottom of *e* into P^1, through the upper channel into P^2, through the lower channel into P^3, and finally escapes by the burner g^1. During the second hour the cocks $s\,s^2$ must be closed, and the cocks $s^1\,s$ being opened, the current goes in the opposite direction and escapes by the burner *g*, where it may be ignited. The changing of the direction of the current dispenses to a certain degree with the labour required for stirring up the matter contained in the pipes: but it may, however, be necessary to pass an iron rod amongst the substances in the pipes, for which purpose the apertures are formed so as to be readily opened and closed.

By substituting soda for potash in the above process, prussiate of soda may be obtained.[1]

In the Jury Report (Class II.) is an interesting account of an attempt made to employ the nitrogen of the air in this manufacture. The communication was made to Professor Graham by Mr. F. R. Hughes of Borrowstowness. He states that in 1844 his firm commenced a series of experiments upon the large scale, at Newcastle, in company with Messrs. Bramwell, to manufacture prussiate of potash without animal matter, substituting the nitrogen of the atmosphere for it, and continued the experiments till the latter end of 1847. In these operations a tube or retort of fire-clay was placed in a vertical position in a furnace so constructed that, when the formation of carbonic oxide was prevented, sufficient heat could be obtained to soften a Stourbridge fire-brick throughout its substance when exposed in the flue, or off-go, to the full force of the fire. The lower part of the retort was made of cast-iron, kept out of the vicinity of the fire, and of sufficient length to afford time for the mass heated by the fire to become cool before it was discharged into a cistern placed below, containing water and a protosalt of iron, into which the lower end of the tube dipped. Provision was made at this end of the tube to regulate the periodical discharge of its contents, in whatever proportion was desired. The tube was filled with wood-charcoal saturated with a solution of the carbonate of potash of commerce, and dried. The mixture in this state generally contained about twenty per cent. of potassa (KO). By means of an air-pump the atmospheric air was drawn through the tube of alkalized charcoal in a continuous stream from the top, and discharged below in a state of nitrogen and carbonic oxide. The alkalized charcoal was thus found to become pretty rich in cyanide of potassium; one-half of the alkali of the cyanized charcoal frequently being found, upon testing, to be in combination with cyanogen; so that when all was working well, 36 to 40 cwt. of prussiate of potash were produced in a week by means of 7 or 8 retorts of 10 or 12 feet long in the fire, and 2 feet internal diameter. In the first experiments much narrower tubes were employed, to which the heat was applied only externally; but as both the tubes and charcoal are bad conductors of heat, sufficient quantities could not be operated upon, and it was found necessary to build larger tubes, with fire-bricks of the above dimensions; leaving a circle of small apertures or chinks in the tube, every third or fourth tier of bricks, through which the intensely heated gases, nitrogen and carbonic acid, were drawn from the flue by the action of an aspirator. The mass in the interior of the large tubes was thus made so hot, that an iron rod one inch in diameter became white hot when thrust down in the centre and allowed to remain there 5 or 10 minutes. The next improvement was to use the alkalized charcoal undried, and to aspirate the air from below upwards, instead

(1) Newton's London Journal of Arts and Sciences, vol. xxi. 1843.

of downwards; the surplus heat drying the alkalized charcoal before it reached that part of the retort in which the cyanide was produced, a length of 6 to 8 feet. The top of the retort was in this case rendered air-tight, and the cyanized mass discharged below as before. Through 7 or 8 retorts of the above size about 2,400 cubic feet of alkalized charcoal were passed in a week, and about 1,200 to 1,400 cubic feet of cyanized charcoal were obtained, nearly one-half of the charcoal being consumed. There were two great drawbacks to this process—one, the immense quantity of material to be lixiviated for a small return of prussiate; the other, and by far the more important, an extraordinary waste of potash in the process, upwards of three parts by weight being consumed in producing one of prussiate. The whole of this waste could never be properly accounted for. About one part of potash was recovered in the state of prussiate. It was found that another part was lost in the small refuse charcoal, which could not be lixiviated to pay, and the remainder appeared to be partly combined with the bricks of the retort, and partly dissipated by the chimney. In 1847 the plan was abandoned after a loss of many thousand pounds. But the possibility was proved of producing large quantities of cyanide of potassium, by drawing intensely-heated nitrogen and carbonic acid gases through a mixture of potash and charcoal, with the difficulty of carrying this out as a manufacturing process from the great waste of potash.

These experiments were more directed to making the air process practicable, for the purpose of manufacture, than to ascertain upon what principle the formation of cyanogen depended; for it was immaterial, in a manufacturing point of view, whether the cyanogen were produced from the nitrogen of the atmosphere, or from the ammonia which the charcoal was always found to contain. The means of nicely observing the changes were lost, from the necessity which existed in operating upon large masses, to draw the intensely-heated gases from the fire into the body of the tubes in order to bring the alkalized charcoal to a proper heat for the production of cyanide of potassium. It is probable, that some part, at least, of the cyanogen was furnished from the ammonia in the charcoal, which in separate experiments in the laboratory was found not to be entirely given off at a red heat. Some alkalized charcoal, also brought to a proper heat in a porcelain tube, produced a considerable quantity of cyanide of potassium without the presence of air, the ends being stopped up. On the other hand, when the retorts were filled with charcoal *not alkalized*, and the heated gases drawn through, no formation of either cyanogen or hydrocyanite of ammonia could be detected.

A paper by Professor Marchand, in the "Chemical Gazette," vol. viii., on the presence of nitrogen in cast-iron and steel, appears to throw some light upon the subject. He has shown that when carbon is combined chemically with iron, and treated with potassium, in the presence of nitrogen, cyanogen is produced. Mr. Hughes thinks it probable that the first step in their process was the formation of a carburet of potassium, which, by combining with the aspirated nitrogen, produced the cyanide of potassium. This might be ascertained by examining the remainder left in the retort, after the production of the potassium in the ordinary way from bitartrate of potash, testing the quantity of cyanide it contained, if any, and then testing the increased quantity after heating it in nitrogen gas. In the foregoing process soda was substituted for potash with a similar loss.[1]

Messrs. Bramwell, of Newcastle-upon-Tyne, are extensive manufacturers of Prussian blue. Their factory was established about 80 years ago, and for a considerable period a large quantity of the pigment was sent every year to China. A spring shipment was made of about 2,000*l.* in value, which was often followed by another in autumn. It was first sold at 2 guineas per pound, made up in neatly finished one-pound packages, but had fallen in 1815 to 10*s.* 6*d.*, and about 1820 to 2*s.* 6*d.* For the last ten years the price of Prussian blue has been 1*s.* 9*d.* per lb. It has been stated that the chief demand for Prussian blue in China was for the purpose of colouring green teas. It must not, however, be forgotten that blue is the favourite colour of the Chinese. The cause of the cessation of the trade is curious. A common Chinese sailor who was brought to England in an East Indiaman, had occasion to visit a Prussian blue manufactory, and thus learned the art of making it. On his return to China he set up as manufacturer of the article, and was so successful that in a short time the whole of China was supplied with the article by native manufacturers.

Prussiate of potash was not known in commerce in a crystallized state until about the year 1825, when it was sold at 5*s.* per lb. For some years before that date a weak solution of the salt, or of the fluxed mass of animal matter and potash, had been sold at 1*s.* per gallon. The rapid progress of the manufacture will appear from the following estimate of the annual production in the United Kingdom:

Annual Production.				*s. d.*	
From 1825—1830	about	10	tons at	5 0	per pound.
1830—1835	,,	40	,,	2 6	
1835—1840	,,	200	,,	1 4	
1840—1845	,,	700	,,	1 4	
1845—1850	,,	1040	,,	1 3	

There are eleven prussiate works in the United Kingdom, of which the aggregate produce is, when the salt is in demand, about 20 tons per week. The two largest works are those of Messrs. Bramwell and the Hurlet and Campsie Alum Company. The value of the annual product for the last 5 years is estimated at 145,600*l.*

PRUSSIC ACID. This compound, so remarkable for its poisonous properties, is a *cyanide of hydrogen*, HCy, and from its acid reaction is also named *hydrocyanic acid*. It was discovered by Scheele in

(1) The above process was considered to have succeeded in a chemical point of view, but was not sufficiently economical for the manufacturer, chiefly because the fire-clay tube did not long resist the combined action of the alkali, and of the excessive heat.

1782. The pure anhydrous acid may be prepared in the following manner. A long glass tube is filled with dry cyanide of mercury, and is connected at one end with an apparatus for furnishing dry sulphuretted hydrogen gas, while to the other end is attached a narrow tube which is passed into a narrow-necked bottle plunged into a freezing mixture. On applying a gentle heat to the tube the cyanide of mercury is decomposed in contact with the sulphuretted hydrogen, with the production of sulphide of mercury and cyanide of hydrogen, the latter being condensed in the cold bottle in the liquid form. To prevent the product from being contaminated with sulphuretted hydrogen, a portion of the cyanide of mercury is left undecomposed. The pure acid is a thin, colourless, volatile liquid: its density at 45° is 0·7058 : it boils at 79°, and solidifies when cooled to zero: its odour is powerful and characteristic, resembling that of peach blossoms or bitter almond oil; it has but a feeble acid reaction, and mixes with water and alcohol in all proportions. It is a powerful poison even when largely diluted with water, and its vapour, if only slightly inhaled, produces giddiness and headache. Ammonia and chlorine are the best antidotes. It is difficult to preserve the acid in its pure form; it soon darkens and deposits a black substance containing carbon, nitrogen, and probably hydrogen, while ammonia and other products are disengaged. The decomposition is greatly assisted by exposure to light. The dilute acid is also subject to decomposition, but in a less degree.

There are various methods of obtaining the hydrous acid. When large quantities are required the best method is to decompose at a boiling heat the yellow prussiate of potash by means of dilute sulphuric acid. The prussic acid made in this way is less liable to decomposition than that above described. The addition of a few drops of hydrochloric acid will also preserve the dilute prussic acid.

Various parts of many plants belonging to the great natural order, *Rosaceæ*, such as bitter almonds, the kernels of plums and peaches, the leaves of the cherry laurel, &c., yield on distillation with water a sweet-smelling liquid containing hydrocyanic acid. "This is probably due in all cases," says Mr. Fownes, "to the decomposition of the *amygdalin* preexistent in the organic structure. The change in question is brought about, in a very singular manner, by the presence of a soluble azotised substance, called *emulsin* or *synaptase*, which forms a large proportion of the white pulp of both bitter and sweet almonds. This substance bears a somewhat similar relation to amygdalin, that diastase, which it closely resembles in many particulars, does to starch. Hydrocyanic acid exists ready formed to a considerable extent in the juice of the bitter cassava."

PUG-MILL.—See Brick—Pottery and Porcelain.

PULLEY.—See Statics.

PUMICE-STONE. Pumice is regarded as a vesicular variety of OBSIDIAN. It has a finely cellular, spongy texture, and is often sufficiently light to float in water. The minute cells being long and fine, it appears as if it had a fibrous structure. It occurs near volcanos which produce felspathic lavas, and its light and cellular structure appears to be due to the inflation of volcanic steam or gas. Its colours are white, grey passing into yellow, brown or black. The pumice from Lipari was found to consist of silica 77·50, alumina 17·50, potash and soda 3, peroxide of iron 1·75. As much as 6·21 per cent. soda, and 3·98 potash has been found in pumice from Ischia. It is largely exported form Campo Bianco, one of the Lipari islands, where it forms a hill from 800 to 1,000 feet high, and from the Ponza islands. At Andernach on the Rhine pumice is used as a building stone.

Pumice-stone is much used in various branches of the useful arts for dressing leather, grinding and polishing the surfaces of metallic plates, and in the state of powder for polishing various articles of cut glass. It is reduced to powder by crushing it under a runner and sifting, in which state it is used for brass and other metal works, and also for japanned, varnished and painted goods; for the latter purposes it is applied on woollen cloths with water.

PUMP. The pump is usually defined as a hydraulic machine for raising water by atmospheric pressure. It will, however, be found in an extended view of pumps that this definition is too limited. We will, however, first speak of common pumps, to which the definition does apply, and in these we shall find much that is ingenious and highly scientific, although they were invented long before the principle of atmospheric pressure was known: indeed it was the lucky accident of a pump being at fault which led to the discovery of that important principle. Professor Robison[1] regards the pump as "the last step in the progress of man's ingenuity for raising water." Nothing like it is known among rude nations: it was not even known in China until the time when Europeans visited that country, and it is still rarely seen in those parts of Asia which are not frequented by Europeans. It does not appear to have been known to the early Greeks and Romans, but may have come from Alexandria, where the physical and mathematical sciences were cultivated by the Greek schools under the protection of the Ptolemies. Pliny and Vitruvius refer to the performances of Ctesibius and Hero as curious novelties. The Egyptian wheel was for many ages in common use all over Asia, and it is still employed in many parts: it was brought by the Saracens into Spain, where it has continued to be used under the ancient name of *noria*. Some years ago certain Danish missionaries found in Siam what Dr. Robison calls the "immediate offspring" of the noria. It was a wheel turned by an ass, and carrying round, not a string of earthern pots as in the noria, but a string of wisps of hay which were drawn through a wooden trunk, forming a sort of rude chain pump. It is used for watering the rice fields. This machine is probably of great antiquity, and may be regarded as the

(1) *Mechanical Philosophy*, vol. ii. This chapter on the Pump forms the article PUMP in the *Encyclopædia Britannica*.

immediate predecessor of the common pump, or rather of the *forcing pump*, which is simpler in its structure than the common *household* or *suction pump*. The forcing pump is shown in section Fig. 1771. It consists of a working barrel in which a tightly fitting piston P works up and down. At the bottom of the barrel is a pipe leading down into the well or pond, the pipe being furnished with a strainer at the bottom to keep out stones and gravel. The hole or point of junction between the barrel and the pipe is closed by a valve *v*. Opening upwards and passing out from the side of the barrel is an ascending tube T, also closed at the point of junction by a valve *v*, opening outwards.

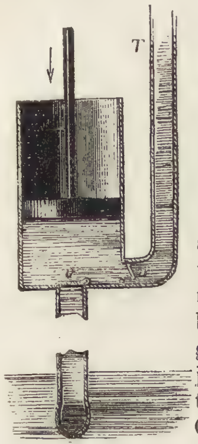


Fig. 1771.

Bearing in mind the law of atmospheric pressure as explained under AIR, and the action of valves in the exhausting and condensing syringe, Fig. 19, and in the air-pump, Fig. 20, the action of this pump will be readily understood. Supposing the piston to be at the bottom of the barrel, and to be drawn upwards, a vacuum, or empty space, would evidently be left between the bottom of the piston and the bottom of the barrel, were it not that air from the pipe forces open the valve at the bottom of the barrel and follows the piston. But in proportion as the air quits the pipe water enters it, and remains suspended therein by atmospheric pressure acting on the surface of the water in the well. The piston, having been raised to the top of the barrel, is now forced down, the lower valve closes, and the air in the barrel forces open the side valve and escapes. On again raising the piston, the barrel is again filled with air from the pipe, and is again expelled by the side tube when the piston is driven down. In this way, by a few strokes of the piston, the whole of the air is drawn out of the pipe, and water rises in its place, provided the height does not exceed 34 feet, at about which height it is balanced in the pipe by the pressure of the atmosphere on the surface of the water in the well. As that pressure is equal to about 15 lb. on the square inch of surface, so a column of water in the pipe, equal in sectional area to 1 square inch, and about 34 feet high, will weigh 15 lb., and thus the atmospheric pressure and the column of water counterbalance each other. If the pressure of the air, as indicated by the barometer, fall below 30 inches of mercury, it will not amount to 15 lb. on the square inch, and consequently will not support 34 feet of water, but a foot or two less; so also if the pipe, leading from the working barrel to the well, exceed 34 feet in length, no water can be drawn, because the atmospheric pressure is not under ordinary circumstances capable of counterbalancing a larger column than about 34 feet of water. [See BAROMETER.] But to return to the forcing pump, Fig 1771. Supposing water to have followed the piston in its upward motion, it is evident that, in the down-stroke, the bottom valve will be closed, and the side valve open, and the water urged by the force of the piston will pass through the side valve and ascend the tube T. On raising the piston, the side valve will close, and prevent the water in T from returning into the barrel. By continuing these actions, drawing up water from the well during the up-stroke of the piston, and forcing it up the tube T during the down-stroke, water can be raised or forced to a considerable height above its level. This, then, is probably the simplest form of pump. The structure becomes a little more complicated in the suction pump, Fig. 1772; for here, in addition to the valve closing the bottom of the barrel, there is a valve in the working piston which alternates in its action with the bottom valve. Thus, on raising the piston in the direction of the arrow, the bottom valve opens and draws, first, air, and then water, from the pipe leading into the well. On lowering the piston the bottom valve shuts, and the piston valve opens, and allows the air or water to pass through the valve and occupy a position above the piston. This state of things is shown in the right-hand figure. The piston having arrived at the bottom of the barrel is again raised; air from the pipe opens the lower valve and follows the piston, water supplies the place of the air drawn out of the pipe; this second portion of air is expelled from the barrel by lowering the piston, and thus, by a repetition of these actions, all the air is drawn out of the pipe, and water follows the ascent of the piston, on lowering which, the water opens the valve, accumulates above the piston, and as this is raised it flows over by the spout, the flow being continuous so long as the pump-handle is worked.

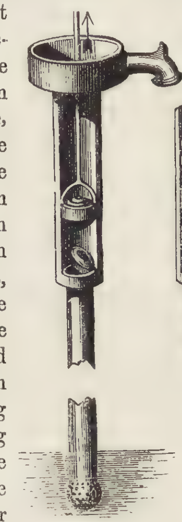


Fig. 1772.

The form and arrangement of the piston are of great importance, and have been explained by Dr. Robison, in the following terms:—“The piston is a sort of truncated cone, generally made of wood not apt to split, such as elm or beech. The small end of it is cut off at the sides so as to form a sort of arch by which it is fastened to the iron rod or spear. [See Fig. 1773.] The two ends of the conical part may be hooped with brass. The cone has its larger end surrounded with a ring or band of strong leather, fastened with

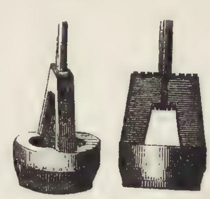


Fig. 1773.

nails, or by a copper hoop, which is driven on it at the smaller end. This band should reach to some distance beyond the base of the cone; the further the better: and the whole must be of uniform thickness all round, so as to suffer equal compression between the cone and the working-barrel. The seam or joint of the two ends of this band must be made very close, but not sewed or stitched together. This would occasion bumps or inequalities, which would spoil its tightness; and no harm can result from the want of it, because the two edges will be squeezed close together by the compression in the barrel. It is by no means necessary that this compression be great. This is a very detrimental error of the pump-makers. It occasions enormous friction, and destroys the very purpose which they have in view, viz. rendering the piston air-tight; for it causes the leather to wear through very soon at the edge of the cone, and it also wears the working-barrel. This very soon becomes wide in that part which is continually passed over by the piston, while the mouth remains of its original diameter, and it becomes impossible to thrust in a piston which shall completely fill the worn part. Now, a very moderate pressure is sufficient for rendering the pump perfectly tight, and a piece of glove-leather would be sufficient for this purpose, if loose or detached from the solid cone; for suppose such a loose and flexible, but impervious band of leather put round the piston and put into the barrel; and let it even be supposed that the cone does not compress it in the smallest degree to its internal surface. Pour a little water carefully into the inside of this sort of cup or dish, it will cause it to swell out a little, and apply itself close to the barrel all round, and even adjust itself to all its inequalities. Let us suppose it to touch the barrel in a ring of an inch broad all round. We can easily compute the force with which it is pressed. It is half the weight of a ring of water, an inch deep, and an inch broad. This is a trifle, and the friction occasioned by it not worth regarding: yet this trifling pressure is sufficient to make the passage perfectly impervious, even by the most enormous pressure of a high column of incumbent water: for let this pressure be ever so great, the pressure by which the leather adheres to the barrel always exceeds it, because the incumbent fluid has no *preponderating* power by which it can force its way between them, and it must insinuate itself precisely so far, that its pressure on the inside of the leather shall still exceed, and only exceed, the pressure by which it endeavours to insinuate itself; and thus the piston becomes perfectly tight with the smallest possible friction. This reasoning is perhaps too refined for the uninstructed artist, and probably will not persuade him. To such we would recommend an examination of the pistons and valves contrived and executed by that Artist, whose skill far surpasses our highest conceptions, the all-wise Creator of this world. The valves which shut up the passages in the veins, and this in places where an extravasation would be followed by instant death, are cups of thin membrane, which adhere to the sides of the channel about half-way round, and are detached in the rest of their circumference. When the blood comes in the opposite direction it pushes the membrane aside, and has a passage perfectly free. But a stagnation of motion allows the tone of the (perhaps) muscular membrane, to restore it to its natural shape, and the least *motion* in the opposite direction causes it instantly to clap close to the sides of the vein, and then no pressure whatever can force a passage.[1] What we have said is enough for supporting our directions for constructing a tight piston. But we recommend thick and strong leather while our present reasoning seems to render thin leather preferable. If the leather be thin and the solid piston in any part does not press it gently to the barrel, there will be in this part an unbalanced pressure of the incumbent column of water, which would instantly burst even a strong leather bag; but when the solid piston, covered with leather, exactly fills the barrel, and is even pressed a little to it, there is no such risk; and now that part of the leather band which reaches beyond the solid piston performs its office in the completest manner. We do not hesitate, therefore, to recommend this form of piston, which is the most common and simple of all, as preferable, when well executed, to any of those more artificial and frequently more ingenious constructions which we have met with in the works of the first engineers."

The piston is sometimes formed of flat discs of leather or of felt, perforated in the centre for fitting on the piston-rod. These discs are pressed together between 2 metal plates, which move upon a worm at the end of the rod, so as to allow them to be screwed up tight, and by this means the edges of the discs are made to present an equable cylindrical surface exactly corresponding with the working barrel in which it moves.

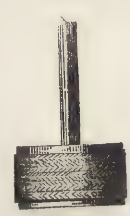


Fig. 1774.

The form of the valve is also subject to considerable variation. The *trap-valve a*, Fig. 1775, is a very common form. It is simply a plate of metal, moving on a hinge, and covering or closing the hole in the bottom of the working-barrel. In order to do this more effectually its under surface is covered with leather: sometimes, in order to increase the mobility of the valve, the hinge itself is of leather, in which case the leather is attached by a plate of metal to the fixed part about the hole, and weight and solidity are given to the leather by means of a plate of metal over the hole as before. At *b* is the section of a *conical-valve*,

(1) It has been suggested to us that Dr. Robison in this illustration is not so happy in his reasoning as usual. "The valves in the veins have no tendency to prevent *extravasation* or escape of blood from the vessels, but tend solely to prevent its return in the wrong direction. His description of the valves hardly conveys the impression of small cup-like folds of membrane opening a free passage, by compression against one side of the vein, for blood passing in the right direction; that is, pressing against the outside of the cup; but spreading out and expanding so as to press against each other or against the opposite side of the vein when the blood tends to enter the inside of the cup and thrust it outward."

consisting of a horizontal section of a cone fitting a conical hole in the bottom of the barrel: the valve is supported on a guide-rod which passes through an arm fixed across the under-side of the barrel. In working the pump, this valve admits of being raised to the extent of the guide-rod by the air or the water pumped up, and it falls by its own weight into its place when the action is over. At *c* is a *ball* or *shot-valve,* which acts in the same manner as *b*, but being spherical, it fits the part which it is intended to close in any position without the assistance of a guide-rod.

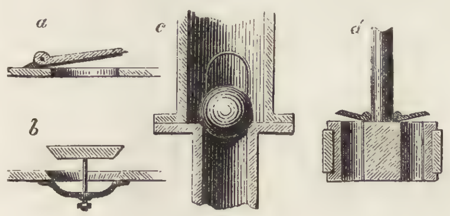


Fig. 1775.

It is necessary, however, to prevent the ball from being carried too high, to place a curved wire or detent at a certain distance above it. The ball may be hollow or solid, or loaded within with some heavy metal so as to adjust it to the work which it has to do. At *d* is a *butterfly-valve,* adapted to the piston: it is similar to *a*, only double.

It will be evident from the foregoing details, that in the erection of a pump the depth of the well is a matter of great importance, for if the distance between the body of the pump and the surface of the water exceed 34 feet, no water will ever be raised, since the atmospheric pressure is never capable of supporting a higher column than 34 feet of water. In practice, however, considerable deductions must be made from this limit. Supposing even that the working parts could be made so perfect as to produce an absolute vacuum in the suction-pipe, Fig. 1773, the varying pressure of the air would only occasionally allow so high a column as 34 feet to be raised. The barometric column in England varies between 28 and 31 inches in height, and this does not represent an average of more than 30 feet in a column of water. If, therefore, the surface of the water to be raised exceed this depth below the level of the ground, it will be necessary to erect the body of the pump in the well at a certain moderate distance from the surface, and to lengthen the piston-rod so that it may be conveniently worked from the surface. This is the arrangement adopted for raising the drainage water from mines. A force-pump, similar in principle to that shown in Fig. 1772, is used. The pump-body is erected at the bottom of the mine, and dips into the sump in which the waters are collected for the purpose of being raised. The pipe T might, in theory, be at once carried to the surface, however deep the mine, if it were possible to make the piston P water-tight, and the cylinder, or body in which it works, sufficiently strong to bear the required force: but as the first of these conditions is not practicable, the plan adopted is to divide the column into a certain number of stages, a distinct force-pump passing from one stage to another. A rod R R, Fig. 1776, descending from the surface to the bottom of the mine, has attached to it, at certain intervals, piston rods, *p p'*, each with a piston fitting into a pump-body *v*, which dips into a cistern C. By the action of the steam-engine, or other motive power, on the surface, the rod R R is moved up and down, whereby motion is imparted to the pistons *p p'*: water is first raised from the sump, forced up the pipe, and discharged into a cistern C: the pump body of the next superior force-pump dips into this cistern: as the rod R moves up, a valve below *v* opens and admits water from C into the pipe; the rod R then moves down, the valve below *v* shuts and the valve *v* opens; and by continuing these actions, water is raised higher and higher in the pipe, and at length overflows into C', which, in its turn, serves as the well to the force-pump immediately above it. It must be remarked, that in this arrangement no more force is expended than would be required for raising water by a continuous tube T, Fig. 1772, to the same height; but with the unbroken tube T there would be the serious defect to which we have already referred.

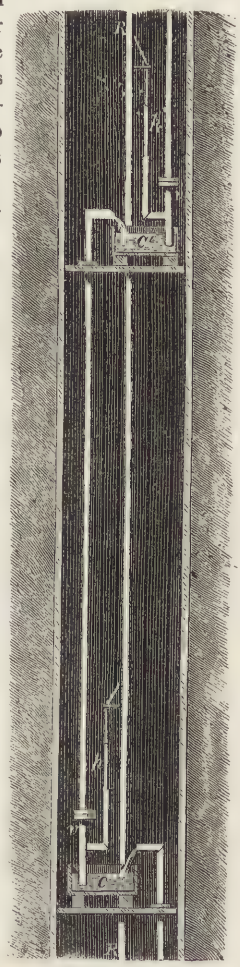


Fig. 1776.

Force-pumps have, however, been constructed capable of raising water upwards of 500 feet above the level of the source, as in the *pumps of Marly,* erected for supplying Versailles with water from the Seine. A section of one of these pumps is represented in Fig. 1777. It consists of a metallic piston P, of much greater length than diameter, moving water-tight through a stuffing-box, and passing into the body of the pump with a considerable range, but without being in contact therewith. The suction-pipe is closed by means of two valves *v v*, and there is also a valve *v'* in the force-pipe. When the piston P is raised a vacuum is left behind it, which is instantly filled by the ascent of water through *v v*. During the ascent of P the valve *v'* is closed, but in its descent *v v* are closed, and *v'* opened, and water is forced along and up the force-pipe to the reservoir situated at the height of 155 metres, or about 508½ feet above the suction-pipe. Now there is a curious

source of inconvenience arising in pumps of this construction which has to be provided against. Water exposed to the atmosphere absorbs a notable quantity of that fluid, which may be made very evident by placing a tall glass of cold water under the receiver of an air-pump and exhausting the air. A portion of the dissolved air is also set free on agitating the water containing it. Now as the water rushes through the valves *v v*, a portion of this air is set free and escapes up into the narrow space between the piston and the interior of the pump cylinder, displacing from that space the water which is necessary to the proper action of the pump, for it is this water which forms the fulcrum or point of resistance in forcing the water up the force-pipe. The first action of the descending piston is therefore to compress this air, so as to make its elastic force correspond with the pressure produced by the column of water in the ascension-tube, and until this takes place no water can be forced through the valve *v′*. Hence not only is the function of the piston greatly deteriorated, and less water forced up the tube than would be if no air existed around the piston, but the height of the column may be so far diminished that the water does not reach up to the reservoir which it is required to fill. To get rid of these objections it is necessary to provide means for removing, from time to time, the accumulation of air in the space around the piston; for which purpose the piston is perforated with a channel *t*, shown by the dotted lines, opening at its lower extremity into the space surrounding the piston, and closed at the top by a stop-cock *h*; so that all that is necessary is occasionally to open this stop-cock, when the piston is at its lowest point and the air most compressed, and the air will then rush out through *t*, and its place be supplied by water. The column of water contained in the ascension-pipe, when at rest, produces a pressure equal to 15 atmospheres = 225 lb. on the square inch. The piston, however, has to overcome a pressure equal to 17 atmospheres, the resistances occasioned by the motion of the water in the pipes producing an increase of pressure equal to 2 atmospheres.

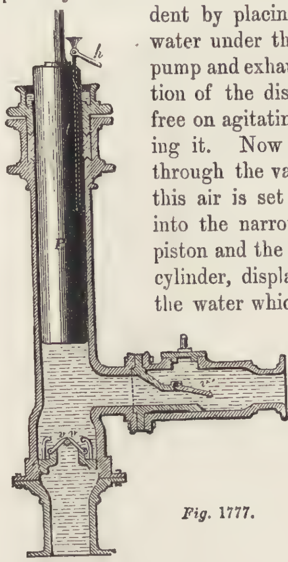


Fig. 1777.

In pumps for domestic use, where it is required to force water into the upper floors, the suction pump and the force pump are combined, as shown in Fig. 1778. The *brake* or pump-handle B moves upon an axis at A, so arranged that, on working the brake, the point A′ shall move up and down, but in a contrary direction; when B is raised A′ is depressed, and *vice versâ*. Attached to a joint at A is a rod *r*, moving in a guide and adjusted to the proper length by the nut *n*: attached to the lower extremity of this rod is the piston P; the suction-pipe T passes down into the well as before. Now it is evident that by the motion of the piston-rod up and down water will be raised into the pump barrel, as in the common pump; during the upward motion of the water the two valves *v v* will be raised, and water will be discharged from the cock near the upper *v*; during the downward motion the two valves *v v* will be closed, and the water below the piston will force open the piston-valve and rise above it; so far the action is the same as in the common pump. If now the cock near the upper *v* be closed and the action continued, then water will rise in the tube T, as in the ordinary force pump.

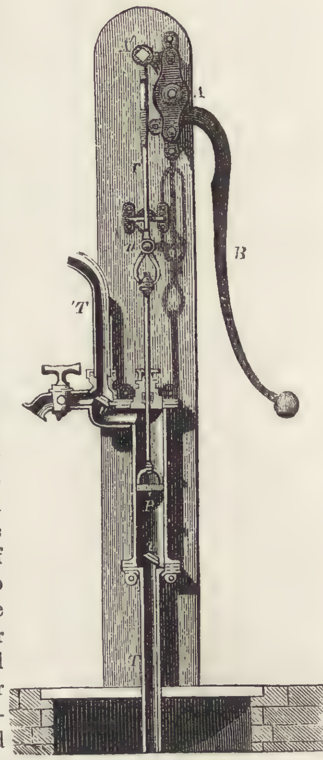


Fig. 1778.

In the pumps hitherto described, the motion of the water is intermittent, either in the suction-pipe or in the force-pipe. In the suction-pipe the water moves only when the piston is ascending, and in the force-pipe only when it is descending. This occasions a great loss of power; for not only must the water be put suddenly into motion after each stroke, but the velocity acquired by the motion of the water in the pipe is not turned to account in doing work. Indeed, it appears from the experiments of M. Morin that the amount of power lost in lifting and forcing pumps amounts to from 55 to 80 per cent. of the whole. "So that of the work (in pounds one foot high) done by the motive power to drive the pump only 45 per cent. in the best and 18 per cent. in the worst pumps, is found to be yielded, when the weight of water actually raised in pounds is multiplied by the height to which it is raised in feet, the rest of the work being lost in the passage of the water through the pump." The causes of this loss of power may be sought, 1. In the small size and peculiar construction of the valves. 2. In the proportion of the section of the barrel to that of the suction and force-pipes. 3. In the form of the suction-pipe at the extremity where the water enters it, and of the force-pipe at

the extremity where the water is discharged. 4. In the forms of these pipes where they unite with the barrel. 5. In the proportion of the length of the barrel to the depth from which the water is raised. There is no doubt that the loss of power would be greatly lessened by increasing the size of the valves, so as to diminish that sudden variation in the section of the stream which is produced by the valves. The small size of the valves also occasions a sudden variation in the velocity of the stream, involving a loss of power varying as the square of the difference of the two velocities, and therefore dependent on the ratios of the sections of the suction-pipe and force-pipe to the section of the barrel. Want of attention to these ratios leads to the second source of loss of power. With respect to the third source, it is well known that the form of the nozzle by which water is discharged from a force-pump greatly influences the amount of the discharge; the form of the extremity of the suction-pipe by which water enters has an equal effect in facilitating its ingress; for it appears that by expanding the extremity of the pipe, by which the water enters, into a cone, of which the diameter of the wider end is 1.2 times that of the other, the *contraction of the vein*[1] may be nearly destroyed, the coefficient of the ingress being increased from ·62 to ·967. That is to say, under similar circumstances tending to cause water to enter the ends of two pipes, one expanded and the other left straight, nearly 10 parts of water would enter the expanded pipe, while about 6 parts were entering the straight pipe. A similar result may be obtained by expanding the extremity by which the water is discharged. By uniting these expedients a discharge may be obtained which is greater than that due to the section of the pipe; thereby practically converting the contraction into an expansion of the fluid vein. The ingress of the water is also facilitated by expanding that extremity of each pipe by which it communicates with the barrel, and the neglect of it leads to a fourth source of loss of power. "A fifth cause to which attention appears not hitherto to have been directed is the loss of power due to the communication of an unnecessary velocity to the water raised. Any one who gives a succession of quick strokes to the piston of a common suction-pipe, allowing sufficient time between them for all the water which can find its way into the barrel to enter it, will find the discharge per stroke to be considerably greater than when the piston is raised slowly. The reason of this is obvious: a certain amount of power, and no more, is required to be done on the piston in order to raise enough water from the well to fill the barrel. If more than this be done, the surplus manifests itself under the form of *vis viva* communicated to the water, by which vis viva, if space be afforded for it to take effect (as in the common suction-pump by efflux from the spout, or by the raising of the valve in the barrel), more water is brought into the barrel than is due to the volume generated by the piston. Half the vis viva of the water under the piston at the end of the stroke measures this surplus work. If a sufficient pause be allowed, and if the head of water above the piston be not considerable, as in the common suction-pump, the upward rush of the water beneath it at the end of the stroke will lift its valve, and a portion of the surplus work (represented by half the vis viva) will take effect in the elevation of more water into the barrel than would fill the space generated by the piston; and thus is explained the fact of the greater discharge from such pumps when worked by quick strokes with intervening pauses, than when worked slowly. If the head of water above the piston be, however, considerable, as in the force-pump, any vis viva which may remain in the water at the end of the stroke will produce a shock and a corresponding loss of power. The shock, commonly experienced in the action of force-pumps, is accompanied by a violent and prejudicial action of the valves, especially when they are of metal. When the down-stroke of the piston follows so rapidly on the up-stroke as to meet the ascending stream produced by the preceding stroke, the resistance to its descent is increased, as well as the loss of power due to the commotion of the particles of the fluid it traverses. It is obvious, therefore, that the proportions of a pump to be worked by a given motive power, should be such that the power to be expended at every stroke may just bring the water raised to rest at the end of each stroke. It is immaterial in what proportions this work is distributed over the stroke, or under what varying degrees of pressure it is generated, provided that the pressure never exceeds that of the atmosphere on the surface of the piston. If this pressure be exceeded, the piston may separate itself from the water beneath it in the barrel, the pump drawing air; and this is more likely to occur at the commencement than at any other period of the stroke, the motion of the water at that point being necessarily slow. To communicate a finite velocity to the water at the commencement of the stroke, or while the space described by the piston is still exceedingly small, requires a much greater pressure than afterwards; and the greater, as the section of the suction-pipe is less as compared with that of the barrel and as the lift is greater. Thus at the commencement of the stroke a finite velocity of the water can only be obtained by an extraordinary effort of the motive power, associated with the chance of drawing air and of a shock, if the pressure be suddenly applied. A remedy for some of these evils in the working of a pump has been sought in the application to it of a second air-vessel communicating with the suction-pipe immediately below the barrel, or with the top of the suction-pipe and the bottom of the barrel. The commencement of each stroke is eased by a supply of water from this air-chamber to the space beneath it. The influx of the water into that space is aided by the pressure of the condensed air in the air-chamber, and when the stroke is completed the state of condensation of this air is, by the momentum of the water in the suction-pipe, restored,

(1) This term is explained under HYDROSTATICS and HYDRODYNAMICS, Fig. 1199.

causing it to rush through the passage by which that pipe communicates with the air-chamber. Thus by this contrivance, the surplus-work, or half the vis viva which remains in the water of the suction-pipe at the conclusion of each stroke, is stored up in the compressed air of the air-chamber, and helps to begin the next stroke of the piston." [1] The nature of the action will be better understood by considering that of the *water ram* described under HYDROSTATICS and HYDRODYNAMICS. Among the pumps of the Great Exhibition the air vessel placed on the suction-pipe was adopted in the *Canadian Fire-engine*,[2] in *Shalders's pump*, and in *Selfe's pump*. In the Canadian engine a distinct copper chamber *a v* was fixed on the suction-pipe *s p*,

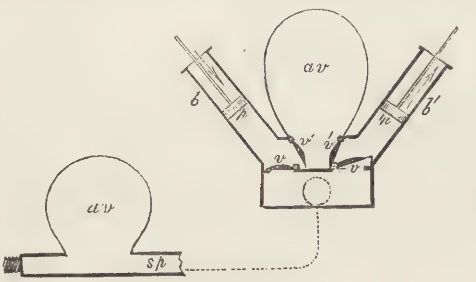


Fig. 1779.

as shown in Fig. 1779. From the action of the pump this suction air-chamber was always about half full of water. This was seen in Selfe's pump, where the air-chamber and pump barrel were of glass. It was seen that in the ordinary pump if a stroke were made very suddenly and rapidly the water could not be started soon enough to follow the piston; but, as it were, lagged behind, leaving a vacuum under the piston, and at the end of the upward stroke the piston went down with a jump, (if tight enough to prevent air being drawn in,) rendering of course all that part of the stroke useless. But with the air-chamber, when a rapid stroke was made, the water in the lower part of the air-chamber was close at hand, ready to follow the piston up, the air above the water expanding to fill the space. Then as soon as the up-stroke was done, and while the down-stroke was being made, the water in the suction-pipe, by the impetus already given to it and by the contraction of the air in the chamber, flowed into this air-chamber and partially filled it as before. So that practically, when pumping very fast and with a large air-chamber, the water is always moving steadily up the suction-pipe, and the pump barrel draws its supplies from the air-chamber in great part. It was found that Shalders's pump when worked very rapidly actually threw *more* water than when worked slowly, evidently from this uniform unchecked motion produced in the rising column of water. Ordinary pumps in such case either draw air or else work in jumps, from the partial vacuum under the piston.

We must also refer particularly to *Letestu's pump* and *fire-engine*, which in the Jury Report are "highly commended for the ingenious, simple, and economical arrangement of the pistons, the large dimensions of the valves, and the large sectional area of the suction and force-pipes, in comparison with the barrel." The piston is a hollow perforated brass cone, to the interior of which is applied a circular piece of leather, like a filtering paper to a funnel, but having a sector cut out instead of being folded: (see Fig. 1780:) the radial edges of the leather overlap, and its periphery projects beyond the edges of the cone, thus adapting itself to the internal surface of the barrel. When the piston is used for suction it is fixed to the rod with the base upwards, as shown in Fig. 1781, and when for forcing with the base downwards, as in Fig. 1782.[3] In the return stroke, the water, passing through the perforations of the brass cone, finds a passage between the loose radial edges of the leather, which it separates. The valve in the air vessel is a simple disc of leather, screwed down at its centre on a perforated plate.

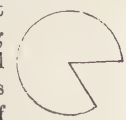


Fig. 1780.

The advantages of these valves lay in the facility with which they could be replaced when injured, and, *secondly*, in their little liability to be choked by sand or gravel drawn in with the water. Both the valves are formed of simple flat pieces of sole-leather without any moulding or bending; and it was found by trial that a new valve, for either place, could be cut out with a common pocket-knife, the old one removed, and the new one put to work in less than five minutes. The piston-valve, as already stated, is a disk with a sector cut out, as in Fig. 1780, so as when folded up to fit inside the cone of brass. *l*, Figs. 1781, 1782, shows this valve secured in the perforated brass cone *c* by the extremity of the piston-rod *r*.

The suction-valve is a simple disk, *v v*, Figs. 1781, 1782, resting on a perforated brass plate, and held by a single screw. In consequence of the surfaces of this valve being pliant and yielding throughout, a piece of sand or gravel, even if it could so rest on one of the light divisions of brass beneath the leather so as to be pressed upon by the leather, would so imbed itself in the leather as not to impede the action of the valve.[4] At *f p* is the force-pipe.

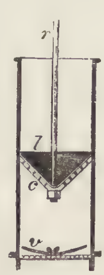


Fig. 1781.

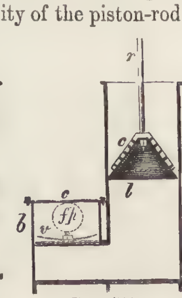


Fig. 1782.

We have already referred to the loss of power occasioned by the intermittent motion of the water in the suction and force-pipes. An uninterrupted flow

(1) Jury Report. Class V.

(2) The *Fire Engine* is described in our article FIRES, *Extinction of*.

(3) In the experiments with Letestu's forcing-pump, it did not lift its own water, but was fixed in a cistern into which the water was poured from buckets, and thence flowed into the barrel from the top as the piston was raised.

(4) In the Jury Report is an account of some experiments with suction-pipes covered with gravel and sand.

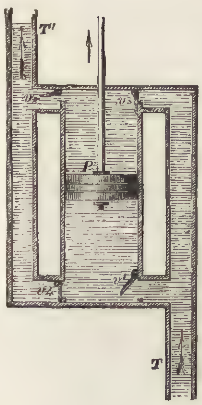


Fig. 1783.

is produced by the arrangement shown in Fig. 1783, which is a very old form of pump. On referring to the force-pump, Fig. 1771, it will be seen, that in the upward motion of the piston water is *drawn up*, and in its downward motion it is *forced up;* but as the piston contains no valve, it was thought that its upper surface might be made to raise or propel water as well as the lower: so that while the lower surface was engaged in drawing water, the upper surface might be forcing it, and *vice versâ.* These effects are produced by the arrangement shown in Fig. 1783. When the piston ascends, as shown in the figure, the valves v^1 v^2 are opened, and water is drawn up the tube T by the lower surface of the piston, and forced up T by its upper surface. When, on the contrary, the piston descends, water is drawn by the upper surface of the piston through the valve v^3, and forced by the lower surface of the piston through v^4. These double-action pumps are seldom used on account of the number of valves required, and their liability to get out of order; so that when a constant stream is required, 2 pumps are used, so arranged with reference to the moving power, that while the piston of one is ascending the piston of the other is descending. Four pumps are sometimes made to work together, in which case, while one piston is at the top of its stroke, the fourth is at the bottom, the second at a quarter, and the third at a half or three-quarter stroke.

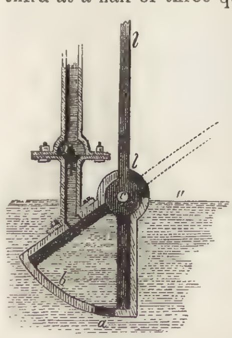


Fig. 1784.

In one description of the *Fire Engine* [see FIRES], a force-pump without a piston is described. A still simpler form is shown in Fig. 1784, in which *l l* is a lever moving round *c* as a centre; the end *c b* works in a box *b* immersed in water, of which *w* is the level. When *l c* is pulled to the left, the end *c b* forces the water from the box up the pipe *p*, and through the valve *v*, where it is kept by the descent of the valve. The water enters the box by the aperture *a*.

A continuous stream is also produced by what is called the *rotatory* or *centrifugal pump.* The history of this form of pump has been traced back for upwards of a century.[1] In its most general form, water, admitted at the axis of a hollow wheel traversed by vanes, and made to revolve rapidly, is expelled at its circumference. The pipe by which the water reaches the axis of the wheel, or the reservoir in which the wheel is immersed, becomes under these circumstances a suction-pipe; and if the reservoir into which the water is received from the periphery of the wheel be closed, and a pipe be carried from it upwards, such pipe becomes a force-pipe. Although, at the time of the Great Exhibition, rotatory pumps were regarded, in England at least, as novelties, they had long been known in France and America, and a very slight research into books on hydraulic machinery was sufficient to make known many varieties of this form of pump, all agreeing, more or less, with the general description just given. For example, Fig. 1785 is a vertical section of the Massachusetts pump in the plane of motion of the elevating blades, and Fig. 1786 is a vertical transverse section of the

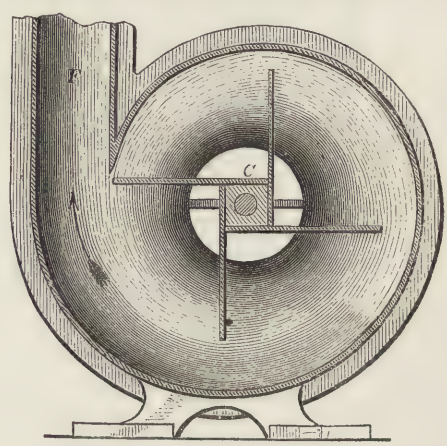


Fig. 1785.

same. This form of pump resembles the ordinary blowing fan: it consists of a short horizontal shaft,

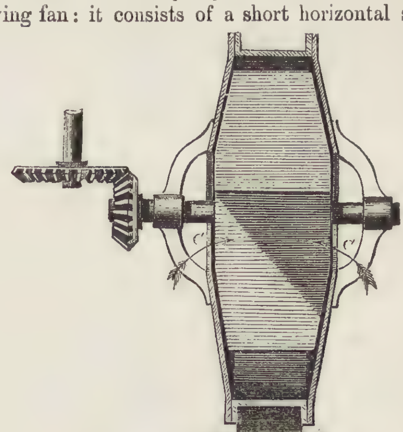


Fig. 1786.

carrying a square boss with 4 eccentric blades set eccentrically within a metal case, from which proceeds

(1) In the *Practical Mechanic's Journal* for September, 1851, is "A Historical Review of the Centrifugal Pump." Although the list of pumps here given is by no means complete, it is of great value. The following are the dates of the inventions, and the names of the inventors. 1732, Le Demour. Date unknown—Inverted Barker's Mill. 1816, Jorge—West. 1818, Massachusetts Pump. 1830, the same improved. 1831, Blake. 1839, Andrews. 1841, Whitelaw. 1844, Gwynne. 1845, Bessemer. 1846, Andrews' Improved—Whitelaw's Improved. 1846, Von Schmidt. 1848, Appold. 1849, Bessemer's Improved. 1850-1, Gwynne's Balanced Centrifugal Pump. 1850-1, Bessemer.

an upright discharging passage F. The apparatus is sunk below the level of the water which is to be lifted, and the vanes being made to revolve by means of the external bevel wheels, the water is sucked in at the central aperture C, and being impelled forwards by the revolving blades, is finally discharged by the centrifugal force through the passage F. It appears, from Fig. 1786, that the vanes are tapered towards their outer extremities.

Fig. 1787 is a form of pump described in several French works. It consists of a wheel C C, mounted

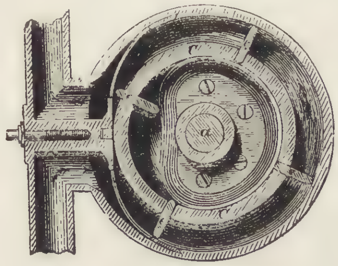


Fig 1787.

on an axis *a*, which corresponds with its centre. This wheel is enclosed within a hollow box or reservoir R R, and is furnished with 4 slots, in which the tongues *e e* are made to slide in by being pressed against the interior surface of the box or case, and to slide out by the pressure of a spring within the wheel. These tongues divide the space R R into 4 compartments. This space is not altogether concentric with C C, but at one part, to the left, it is brought nearer to the centre *a*, so that when the wheel C revolves, the tongues *e e* are forced inwards in passing this contracted part, the effect of which is to vary the capacity of the 4 compartments. There are 2 openings in the box R R to which pipes are attached, one corresponding with the suction-pipe, and the other with the force-pipe of the common force-pump. When, by the rotation of the wheel C C, and the projection of 2 of the tongues, one of the compartments surrounding it becomes enlarged in size, such compartment is at that very moment in communication with the opening leading into the suction-pipe; water, therefore, rises in this pipe and entirely fills the compartment just when it has attained its greatest capacity. As the wheel turns round, and this compartment begins to be contracted, it communicates with the force-pipe by the second opening, and discharges its water accordingly. In this way, by the continued motion of the wheel, water rises into each compartment just as it attains its greatest capacity, and is discharged therefrom into the force-pipe all the time that its capacity is being diminished; and as these two actions are continuous, a constant stream of water is discharged above.

Some old forms of rotatory pump, described by Ramelli and others, are represented in the 3 following figures. In Fig. 1788, a wheel W, with 3 spiral wings, $s\ s'\ s^2$, revolves round a centre C. When *s* ascends towards *r* the water between *s* and *r* is forced up into the pipe *p*, and is prevented from returning by the valve *v*, the rod *r* rising between the guide-rollers *g g* as *s* advances to *r*, for the purpose of preventing the water from getting through at *r*. The next wing, *s'*, produces a similar effect, and carries the water above its natural level *w w* to the pipe *p*.

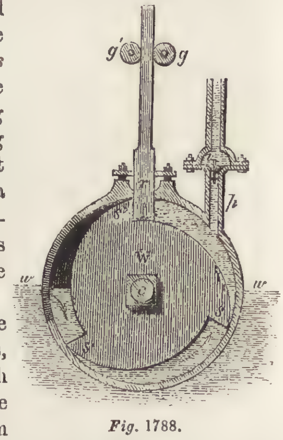


Fig. 1788.

In Fig. 1789 there are 2 revolving wheels, W W', working into each other, and fitting close to the elliptical cistern C C'. The water which rises through the pipe *p* into C is forced by these wheels round the outer teeth, and so up the pipe *p'*. A pump of this kind, with only one wheel, is described in *Nicholson's Journal*, vol. viii.

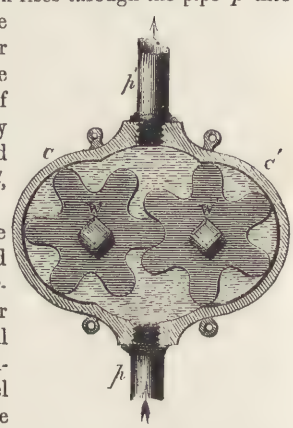


Fig. 1789.

In Fig. 1790 the same effect is produced by a wheel W, furnished with a number of vanes *v v*, which fall down on the circumference of the wheel at the side, and resume their other position by the action of a spring *s* attached to each of them: hence they force the water up from *p* to *p'*.

Fig. 1790

Two centrifugal pumps in the Great Exhibition, one by Mr. Appold and the other by Mr. Gwynne, excited much attention and interesting discussion. Mr. Appold's pump consists of a revolving fan F, Figs. 1791, 1792, 1 foot in diameter, and 3 inches wide, formed of 2 sheets of copper or sheet-iron bevelled outwards towards the centre like shallow dishes. There is an opening one-half the total diameter in the centre of each side, for the admission of the water, and a central division-plate, extending to the circumference, to give a direction to the 2 streams of water, and for the convenience of fixing to the shaft S. Between the outer discs and the centre plate are 6 arms or blades passed through slots in the centre plate, and soldered to the inner surfaces of the outer disks. These arms are curved backwards, and terminate nearly in a tangent to the circumference. The

revolving fan is fixed to the end of the driving shaft s, which passes through a stuffing box in the side of

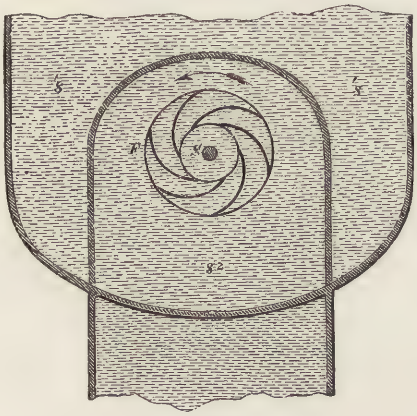


Fig. 1791.

the casing, and the fan is made to work between 2 circular cheeks C C, as close to them as possible without actually touching, the object of these cheeks being to shield the outer revolving surfaces from the water, but at the same time to allow a free

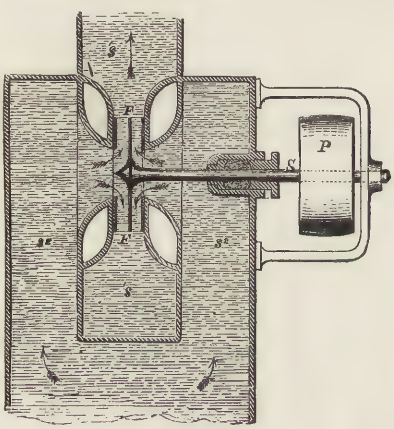


Fig. 1792.

ingress for the water at the centre. To facilitate the escape of the discharged water, a large space *s s* is left round the circumference of the fan. The water to be raised is, as already stated, admitted through the central openings in the outer disks, and the fan being made to revolve with considerable velocity, the water is discharged by the centrifugal force through the openings in the circumference, and so up the force-pipe to the discharge opening.

In Mr. Gwynne's pump, there is one straight radial arm, as shown in Figs. 1793, 1794, which represent a longitudinal and a transverse section. The arms are also straight in Mr. Bessemer's pump, shown in vertical section, Fig. 1795, and plan, Fig. 1796.

A number of experiments were tried at the Great Exhibition on the working power of these pumps. The results are given in the Jury Report in a tabular form, together with the following remarks:—"The greatest economy of power, in such a pump, may be expected to be attained when there is the least possible loss of the vis viva of the water in its access to the wheel, and when there remains the least possible vis viva in it when it leaves it. For if there be any loss of the vis viva of the water in its ingress to the

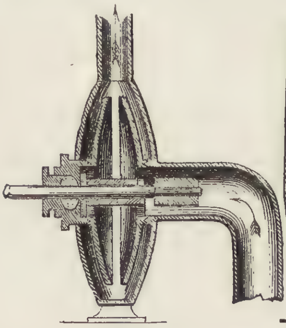


Fig. 1793.

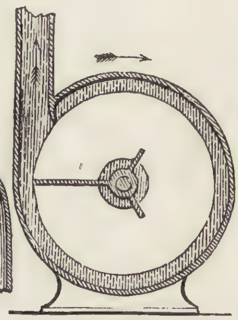


Fig. 1794.

pump which might have been avoided, it is evident that power must have been expended unnecessarily in producing that vis viva. And in like manner, if any vis viva remain unnecessarily in the water when it leaves the wheel, it is evident that the power by which that vis viva was created might have been saved. The expedients by which the water may be brought to the wheel with the least loss of vis viva are common to this and to other hydraulic machines; those by which it enters and is delivered *from* the wheel are peculiar to the centrifugal pump. If the vanes be straight (as at B C, Fig. 1797), it is evident that whatever may be the velocity of the water in the direction of a

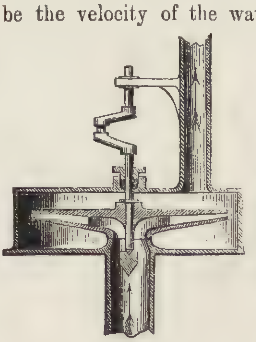


Fig. 1795.

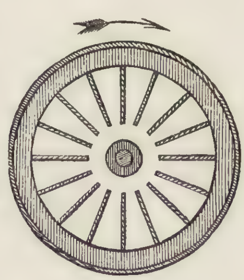


Fig. 1796.

radius, when it leaves the wheel, its velocity in the direction of a tangent will be that of the circumference of the wheel, so that the greater the velocity of the wheel the greater will be the amount of vis viva remaining in the water when discharged, and the greater the amount of power uselessly expended to create that vis viva. If, however, the vanes be curved backwards (as at A, Fig. 1797), as regards the motion of the wheel, so as to have nearly the direction of a tangent to the circumference of the wheel at the points where they intersect it, then the velocity due to the centrifugal force of the water carrying it over the surface of the vane in the opposite direction to that in which the wheel is moving, and nearly in the direction of a tangent to the circumference, will,—if this velocity of the water over the vane in the one direction be equal to that in which the vane is itself moving in the other—produce a state of absolute rest in the

water, and entire exhaustion of vis viva. And in whatever degree the equality of these two motions—of the water in one direction over the vane, and of the vane itself in the opposite direction—is attained, in that same degree will the water be delivered in a state approaching to one of rest.

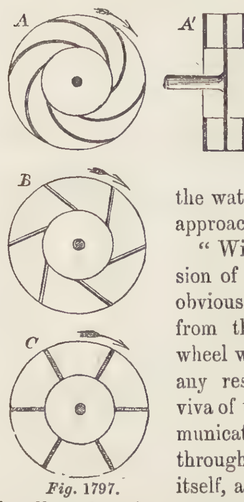


Fig. 1797.

"With regard to the admission of water to the wheel, it is obvious that it should pass directly from the suction-pipe into the wheel without the intervention of any reservoir in which the vis viva of the influent stream,—communicated in the act of rising through the pipe—may expend itself, and that such space should be allowed at the centre as not to alter the dimensions of the influent stream. It would further seem expedient, by means of properly constructed channels, to divide the water into separate streams, and to give to these divergent streams such curvatures as would facilitate their entrance upon the channels formed by the vanes; as in the turbine. It is obvious that the tendency of the centrifugal force continually to increase the velocity of the water over the vanes as it recedes from the centre, cannot take effect in respect to all the particles of water in the same section, unless the sections of the channels diminish. If they do not, some of the particles of water in each section must be continually retarded, and power be uselessly expended in producing this retardation; whilst the current cannot but suffer from it a disturbance destructive of its vis viva. This diminution of the sections of the channels might probably best be effected by giving to the sides of the wheel the forms of conical disks; an expedient which is adopted in Mr. Lloyd's blowing machines and in Mr. Bessemer's centrifugal pump. The communication of motion to the water of the reservoir in which the wheel revolves and into which the water is discharged, should by every practicable expedient be avoided; and for this object the water should be kept as much as possible from the sides of the wheel. This is effected in Mr. Appold's pump by fixing the wheel between two cheeks which project from opposite sides of the reservoir. The velocity with which the wheel must be driven depends upon the height to which the water is to be raised. Beyond a certain height this velocity is practically unattainable. But long before this limit is reached, it becomes inconsistent with an economical application of the power which drives the pump. It is probably therefore only in comparatively small lifts, where a large quantity of water is to be discharged, that the centrifugal pump will be found useful."

The experiments tried with Appold's pump at the Great Exhibition were for the purpose of ascertaining the per-centage of useful effect yielded by it when raising water to different heights. The power employed in each experiment was measured by means of *Morin's dynamometer*,[1] arranged as follows:—The driving strap from the steam-engine was passed over the first pulley of the dynamometer, and the pump was driven from the second pulley running loose on the same shaft and connected to the first by means of a spring, through which all the power was transmitted: the amount of the driving power was therefore indicated by the extent to which the spring was bent, and this was shown by a continuous pencil mark upon a paper cylinder connected to the instrument, and from which the actual tension of the driving strap at all periods of the experiment was accurately ascertained. By this means the following results were obtained:—

Appold's Centrifugal Pump, *with curved arms.* A, *Fig.* 1797.

Per-centage of effect to power.	Height of lift.	Discharge per minute.	Revolution of pump per minute.	Velocity of circumference.
	Feet.	Gallon.		Feet per min.
59	8.2	2,100	828	2,601
65	9.0	1,664	620	1,948
65	18.8	1,164	792	2,488
68	19.4	1,236	788	2,476
46	27.6	681	876	2,751
With straight inclined arms. B, *Fig.* 1797.				
43	18.0	736	690	2,168
With straight radial arms. C, *Fig.* 1797.				
24	18.0	474	720	2,262

At a meeting of the Institution of Mechanical Engineers, held at Birmingham 28th June, 1852, Mr. Appold made some interesting statements respecting centrifugal pumps. He illustrated the superior action of oblique arms, B, Fig. 1797, to radial arms, C, Fig. 1797, by supposing a vertical arm A B, Fig. 1798, to move in a straight line to C D, instead of moving round in a circle in the pump, and the body A, representing a particle of water, would then be simply moved along to C with the arm, without having any tendency to be propelled outwards along the arm to B. But if an oblique arm A E is employed, moving in the same direction as before to the position C B, it propels the particle A outwards towards B, having an inclined-plane action to push the particles of water outwards from the centre towards the circumference. When this was applied to a circular motion, and the direction A C bent into a circle, the inclined arm A E became curved in a spiral direction like the arms in the pump. The comparative value of the different forms of arms proved by the experiments at the Great Exhibition, and as shown in the above table, give a duty of 68 per cent. for curved arms, 43 per cent. for inclined arms, and only 24 per cent. for radial arms. It is stated that the other centrifugal pumps in the Exhibition which had straight arms did not give a higher duty than 24 per cent.[2] With respect to the velocity of

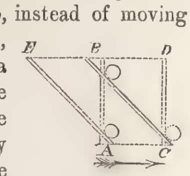


Fig. 1798.

(1) This instrument is described in our Introductory Essay, page cliii. Figs. lxxii—lxxiv.

(2) Although Mr. Appold appears to have been the first practical centrifugal pump maker who fully appreciated the superior value of curved vanes over straight ones, it appears that the curved form was adopted in some pumps erected in the United States of America about 1839; but it is a remarkable fact that curved vanes

the circumference of the wheel, this must be constant for all sizes of pump for the same height of lift: that is, a pump 1 inch diameter must make 12 times the number of revolutions per minute compared with one 12 inches in diameter, and both pumps will then raise the water to the same height, but the quantity of water delivered will be 144 times greater in the 12-inch pump, being in proportion to the area of the discharging orifices at the circumference, or the square of the diameter, when the proportion of breadth was kept the same, namely $\frac{1}{4}$th of the diameter in each case. A small pump 1 inch in diameter gave proportionate results with a pump 12 inches in diameter, the former discharged 10 gallons of water per minute and the latter 1,440, and consequently it is assumed that a wheel 10 feet in diameter would discharge 144,000 gallons per minute. A velocity of the circumference of 500 feet per minute raised the water 1 foot high, and maintained it at that level without discharging any; and a double velocity raised the water to 4 times the height as the centrifugal force was proportionate to the square of the velocity; consequently

Feet per min.		ft.	
500	raised the water	1	without discharge.
1,000	,,	4	,,
2,000	,,	16	,,
4,000	,,	64	,,

The greatest height to which the water had been raised without discharge, in the experiments with the 1-foot pump was 67·7 feet with a velocity of 4,153 feet per minute, being rather less than the calculated height. A velocity of 1,128 feet per minute raised the water $5\frac{1}{2}$ feet without any discharge, and the maximum effect from the power employed in raising to the same height $5\frac{1}{2}$ feet, was obtained at the velocity of 1,678 feet per minute, giving a discharge of 1,400 gallons per minute from the 1-foot wheel. The additional velocity required to effect the discharge is 550 feet per minute; or the velocity required to effect a discharge of 1,400 gallons per minute, through a 1-foot pump, working at a dead level without any height of lift; so that adding this number in each case to the velocity given above at which no discharge takes place, the following velocities are obtained for the maximum effect to be produced in each case:—

Feet per min.		ft.	
1,050	velocity for	1	height of lift.
1,550	,,	4	,,
2,550	,,	16	,,
4,550	,,	64	,,

Or in general terms, the velocity in feet per minute for the circumference of the pump to be driven, to raise the water to a certain height, is equal to

$$550 + (500\sqrt{\text{height of lift in feet.}})$$

Mr. Appold considers that when his pump works at the most effective velocity it yields a duty of 70 per cent. One of the great advantages of a pump of this kind is the ease and celerity with which it can be erected; and situations occur where it is highly important to be able to discharge a very large quantity of water in a short time. For example, in laying the foundations of the harbour works at Dover, a large quantity of water—2,000 to 3,000 gallons per minute—was pumped out by one of these pumps, an effect which could not have been produced in the time by any other means, in consequence of the difficulty and delay of fixing ordinary pumps of great capacity. The centrifugal pump had another important advantage for such applications from having no valves, which enabled it to pass large stones, and almost anything that was not too large to enter between the arms.

The largest pump constructed on the present plan was erected at Whittlesea Mere for the purpose of draining. The wheel is $4\frac{1}{2}$ feet in diameter and its average velocity is 90 revolutions or 1,250 feet per minute; it is driven by a double cylinder steam-engine, with steam 40 lb. per inch, and vacuum $13\frac{1}{2}$ lb. per inch; it raises about 15,000 gallons of water per minute an average height of 4 or 5 feet. The cost of the engine and pump was about 1,600*l*.

The centrifugal pump is more advantageous for low lifts (below 20 feet) than for high lifts. Its most advantageous application is as a tidal pump, where the height of lift is continually varying, because it discharges more water the lower the lift, the pump still going at the same speed. Valve pumps generally discharge their cubic contents only, however low the lift. The centrifugal pump is also a useful adjunct to a water-wheel, to assist in keeping it at work by returning a portion of the water when the supply is short.

PUNCH—PUNCHING MACHINE. In the ordinary acceptation of the word, a punch is a circular or a four-sided or other form of chisel, for making a hole in any thin substance, or for cutting out *blanks*, as for buttons, steel pens, and numerous other objects. Punches may be arranged into two classes, viz. *duplex* and *single*. The former are used in pairs, and partake of the nature of shears. Single punches have usually acute edges with one perpendicular side: but sometimes the edges are rectangular. The punch is driven through the material to be cut by the blow of a hammer, and in order to prevent the cutting edge from being injured the material is placed upon a support of wood, lead, tin, &c. The gun-punch, Fig. 1799, is made by turning, as is the case with most circular punches. It is conical on the outside and nearly cylindrical within, being a little wider at the top to allow the waddings to ascend freely and escape

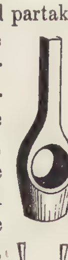


Fig. 1799.

were in most if not all cases rejected for straight ones. In a memoir by M. Ch. Combes, "Sur les Roues de Réaction," read before the Academy of Sciences at Paris on the 23d July, 1838, "the theory of the centrifugal ventilator is discussed, and its obvious relations to the theory of the centrifugal pump are pointed out. The curved form proper to the vanes is insisted on in this paper, and its theory investigated." In 1838-9, M. Combes appears to have taken out a *Brevet d'invention* for a centrifugal pump, a model of which still exists in the collection of the "Ecole Nationale des Mines," at Paris. In 1843 he published a work, "Sur les Roues à réaction ou à tuyaux."

through the upper opening. When such punches are of large size, over 2 inches in diameter, they are made of steel rings attached to iron stems. The punch used for cutting out wafers is a thin cylinder of steel, attached to the end of a perforated brass cone with a cross handle at the top. Lozenges are cut out with a thin steel cutter fixed to a straight perforated handle of wood. "When the disk is the object required, the punch is always chamfered exteriorly, as then the edge of the disk is left square, and the external or wasted part is bruised or bent; but the punch is made cylindrical without and conical within when the annulus or external substance is required to have a keen edge. And when pieces, such as washers, or those having central holes, are required in card or leather, the punches are sometimes constructed in 2 parts, the inner being made to fit the outer punch, and their edges to fall on one plane; so that one blow effects the two incisions, and the punches may then be separated for the removal of the work should it stick fast between the two parts of the instrument."[1]

Various forms of punches are described or referred to in the course of this work.—See COMB—COINING—ENVELOPE-FOLDING MACHINE—FLOWERS, ARTIFICIAL—CUTLERY—BUTTON—PEN—NAIL, &c.

Many forms of punch are for the sake of greater precision in their action furnished with guides. The punch pliers, Fig. 1800, have a round hollow punch with acute edges, and are used for making holes in

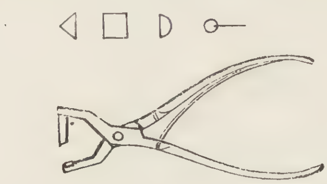


Fig. 1800.

leather straps and thin materials. Some pliers are made with oval punches; others square and triangular. In all such tools the punch closes upon a small block of ivory or copper, and the material being put between the punch and the block and pressure applied, it is cut through without injury to the punch.

The tool shown in Fig. 1801, is of great use in repairing boilers, and in confined situations where larger tools cannot be used, as about the holds of ships. It consists of a stout piece of wrought-iron about 1 inch thick, and about 4 or 5 inches wide, thickened at the ends and bent into the curve shown in the figure. One extremity is tapped for the reception of a coarse screw, the end of which is formed as a cylindrical pin or punch. Opposite the punch is a hole for the reception of a hardened steel ring or bed punch. When the screw is turned round by a lever about 3 feet long, it will make holes as large as $\frac{3}{4}$ inch diameter in plates $\frac{3}{8}$ inch thick. A similar tool made of gun-metal, but weighing only a few ounces, is used for punching the holes in leather straps, for lacing them together by thongs, or uniting them by screws and nuts, as in making the endless bands or belts for driving machinery.

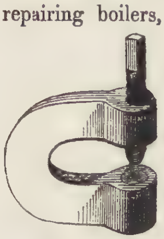


Fig. 1801.

In connexion with punching, the fly-press comes into prominent importance. This most useful apparatus is employed for cutting out blanks, punching holes, moulding, stamping, bending or raising thin metals into various shapes, impressing others with devices as in medals and coins; also in the manufacture of encaustic tiles, tesseræ, &c., and various other objects of great commercial importance. The fly-press is a contrivance for giving a precise and well-regulated blow to the punch, which is guided by moving in a slide: the slide gives precision to the blow, while the required degree of force is imparted to it by the heavy revolving fly attached to the screw of the press.[2] When the fly-press is used for cutting out works it is called a *cutting-press*, to distinguish it from *stamping* or *coining-presses*. The body of the press B, Fig. 1802, is a solid massive piece of iron, attached to a bed or base B′ at right angles to the screw. The latter is coarse in pitch, and has a

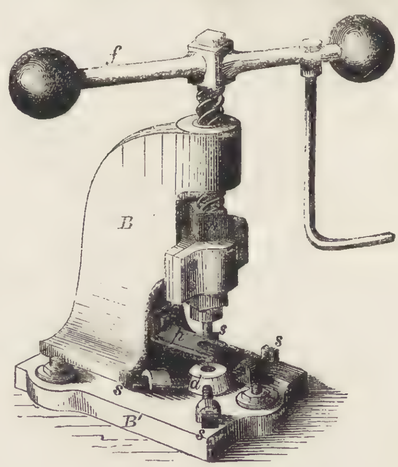


Fig. 1802. CUTTING-PRESS.

double or triple square thread, the rise of which is about 1 to 6 inches in every revolution. The nut of the screw *n* is usually of gun-metal, and is fixed in the upper part or head of the press: the top of the screw is square or hexagonal, and on it is fitted a wrought-iron lever with a solid cast-iron ball at each extremity; the lever and balls forming the *fly*, *f*. From the lever a handle descends to the level of the dies, so that while the operator works the press with his right-hand, his left is at liberty to feed the press. The punch is usually attached to a square bar or follower, which fits into an aperture at the bottom of the screw. A punch is commonly attached by being fitted into a cavity, and retained by a pin or

(1) Holtzapffel, *Mechanical Manipulation*, vol. ii. The reader interested in the subject is recommended to study the chapter on *Punches* in this admirable work.

(2) This is also the principle of the *embossing-press* described under BOOKBINDING, Fig. 174.

side screw; but a die is screwed into the follower. The bed or bottom die *d* is held in its proper position by 4 screws *s s* passing through as many blocks or dogs: the screws point in a slightly downward direction, and by their means the die can be nicely adjusted so as to correspond accurately with the punch. The projecting piece *p*, called the *puller-off*, rests nearly in contact with the die: its office is to detach the sheet of metal from the punch, for after every blow the punch, being passed through the sheet of metal. adheres to it and raises it: but the punch, being elevated above the perforation in the puller-off, is thus released, and the sheet of metal is readjusted over the die preparatory to another blow.

A *punching machine*, as used by engineers, is represented in our INTRODUCTORY ESSAY, Fig. XXVII. It is chiefly used for making the rivet-holes round the edges of the plates for steam-boilers, tanks, and iron ships. It is also used for cutting out curvilinear parts and apertures in boiler work, in which case a series of holes is made with a round punch, the holes being run into each other along the line to be cut through.[1]

PUOZZOLANO. See MORTARS and CEMENTS.

PURPLE OF CASSIUS. See POTTERY and PORCELAIN. SECTION IX.

PUTREFACTION. See FOOD, PRESERVATION OF —FERMENTATION.

PUTTY. The putty used by glaziers for fastening window-glass in the frames, and by carpenters and others for stopping holes in their work, is a mixture of whiting and linseed oil. The whiting is dried, pounded, and sifted, and stirred into a tub containing the oil. When sufficiently stiff, the mass is taken out, placed on a board, and worked by hand, more whiting being added from time to time: it is lastly beaten with a mallet until it is sufficiently smooth and uniform. By exposure to the air it becomes hard and durable.

PUTTY-POWDER, an oxide of tin, or of tin and lead in various proportions, much used in polishing glass and other hard substances. The best putty-powder consists of pure oxide of tin; but as the manufacture of this is difficult, the oxidation is assisted by the addition of a small quantity of lead, for which purpose the linings of tea-chests are employed, or an alloy prepared in ingots by the pewterers, and called *shruff*. Common putty-powder, of good fair quality, is prepared from equal parts tin and lead, or tin and shruff. The inferior dark-coloured kinds are made from lead only. Putty-powder is prepared by placing the metal in an iron muffle kept at a red heat; the metal fuses, the oxide forms on its surface, and it is frequently stirred to expose fresh surfaces to the air. When all the metal has disappeared, the process is at an end, and the upper part of the oxide sparkles like particles of incandescent charcoal. The oxide is removed in ladles, and is spread out in iron cooling-pans. Hard lumps of the oxide are then selected and ground dry under a runner, and the powder thus produced is sifted through lawn. The whitest powder, if heavy, is generally the purest: some of the common powders are brown and yellow: those known as *grey putty* contain a small portion of ivory-black. The pure white putty is preferred by opticians, workers in marble and others: it is the smoothest and most cutting, and answers well as a plate-powder, and for polishing in general. The putty-powder prepared by Mr. A. Ross, the optician, for fine optical purposes, is noticed under LENS.

(1) The punching-engine, contrived by Messrs. Maudslay, Sons, & Field, for manufacturing water-tanks for the Royal Navy, is engraved and described in Buchanan's "Treatise on Mill Work," edited by G. Rennie, Esq. F.R.S. Other punching-engines are also figured and described in the same work.

PYRITES. The native bisulphuret of iron strikes fire with steel, and hence its name, from πῦρ, *fire*, because, as Pliny supposed, "there was much fire in it." Copper pyrites, or *mundic*, is a bisulphuret of copper. See IRON—COPPER.

PYROACETIC SPIRIT. When anhydrous metallic acetates are subjected to destructive distillation, they yield, among other products, an inflammable volatile liquid, which has been named *acetone* or *pyroacetic spirit*. It is readily prepared by distilling dried acetate of lead in a large earthen or coated glass retort, gradually raised to redness. A receiver, kept cold with abundance of cold water, is adapted to the retort. Much gas, chiefly carbonic acid, escapes, and the volatile spirit is condensed in the receiver. Minutely divided metallic lead is left in the retort, and this sometimes acts as a PYROPHORUS. The acetone is slightly contaminated with tar. It is purified by being saturated with carbonate of potash, and it is afterwards rectified from chloride of calcium in a water bath. The pure acetone is a colourless limpid liquid of peculiar odour: its density is .792: it boils at 132°: it is very inflammable, and burns with a bright flame: it mixes in all proportions with water, alcohol, and ether. It consists of C_3H_3O, and is formed by the conversion of acetic acid into acetone and carbonic acid. [See ACETIC ACID.] Acetone is also produced in the destructive distillation of citric acid, and may be procured from sugar, starch, and gum, by distillation in an iron bottle, with powdered quick-lime. In this case it is accompanied by an oily, volatile liquid, separable by water, in which it is insoluble: it is termed *metacetone*, and contains C_6H_5O.

PYROLIGNEOUS ACID, one of the products of the destructive distillation of wood. These products will be considered together under WOOD, DISTILLATION OF.

PYROMETER. See THERMOMETER.

PYROPHORUS, a name applied to those powders which ignite spontaneously on exposure to the air. A very good pyrophorus can be made by means of the tartrate of lead, formed by adding tartaric acid or a tartrate to a solution of nitrate or acetate of lead. This tartrate is a white crystalline powder nearly insoluble. When it is raised to a dull-red heat in a glass tube it becomes brown, and in this state forms a pyrophorus, immediately igniting on being shaken out into the air. This property is to be referred to the rapid oxidation of the minutely divided metallic lead. *Homberg's pyrophorus* is formed by carbonizing, in an

open pan, a mixture of dried alum and sugar, and then heating to redness without contact of air. This compound ignites spontaneously on exposure to air. Finely divided sulphuret of potassium appears to be the essential ingredient.

PYROXILIC SPIRIT. See WOOD, DISTILLATION OF.

QUARRY. See STONE.

QUART, a word applied to the fourth part or *quarter* of a gallon.

QUARTATION. See ASSAYING.

QUARTZ is the mineralogical name of a substance widely diffused throughout nature, as in the numerous varieties of rock crystal or native oxide of silicium, siliceous or flint earth, and silicic acid [see SILICIUM]. Quartz is one of the constituents of granite and of the older rocks. [See INTRODUCTORY ESSAY, p. lxxix.] It also occurs crystallized and massive. The primary form of the crystal is a rhomboid, but it is generally found in hexagonal prisms terminated by hexagonal pyramids, and when the prism is wanting and both pyramids are present, the crystal is a dodecahedron with triangular planes. The cleavage is not usually traceable by ordinary means, but may often be detected by heating the crystal and plunging it in water. The cleavage is parallel to the planes and pyramids of the ordinary crystal. The fracture is conchoidal, hardness 7.0; it scratches glass readily, and gives fire when struck with steel. It becomes positively electrical when rubbed, and two pieces when rubbed together in the dark become luminous. It is transparent, translucent or opaque; the lustre is vitreous or resinous: the specific gravity 2.69 to 2.81. It is infusible, insoluble in most acids; but it combines with the fixed alkalis and produces silicates. [See GLASS, Sec. II.]

Pure quartz is colourless, but quartz usually exhibits a great variety of colours. Purple quartz or *amethyst* occurs both crystallized and massive: it is of every shade of purplish violet: it contains alumina and oxide of manganese. *Blue* quartz or *siderite* also occurs crystallized and massive. The *Cairngorm* or *smoky quartz* contains a small quantity of bitumen. *Green* quartz is found in Peru in translucent hexagonal prisms. Opaque massive green quartz is called *prase:* it is found in Saxony. *Crysoprase* is an amorphous quartz of a light green colour, oxide of nickel being the colouring matter. *Yellow* quartz, called *Scotch*, and *Bohemian topaz* is of various shades of yellow. *Opaque yellow* or ferruginous quartz contains about 5 per cent. of oxide of iron: it occurs in various shades of yellow and reddish yellow. *Red* quartz, or *Compostella hyacinthine* quartz, is of a yellowish or reddish-brown.

For different varieties of amorphous quartz we must refer to AGATE—FLINT—OPAL—JASPER, &c.

QUASSIA. The bark of the *Q. simarouba*, a tropical tree, used in medicine, contains a volatile oil, bitter extract, traces of gallic acid and various salts. The *Q. excelsa*, also used in medicine, contains a peculiar bitter extract, named *quassine.* The medicinal virtues of these trees were first made known by a negro named *Quassy*, and the generic term was given in honour of him. An aqueous solution of *Q. excelsa*, sweetened, makes a good *fly-poison*, very much to be preferred to the usual *fly-waters* which contain orpiment, the yellow sulphuret of arsenic. Should children, attracted by its sweetness, drink the latter they would be poisoned: but they may drink the quassia water with impunity.

QUERCITRON, the bark of the *quercus nigra*, or *tinctoria*, or yellow oak, a native of North America. It is prepared for use by taking off the epidermis and pounding the inner bark in a mill. Its colouring principle, *quercitrine*, forms pale yellow spangles; it has a faint acid reaction, is soluble in alcohol, and to a certain extent in water. A decoction of the bark, deprived of its tannine by means of glue, produces a fine yellow upon fabrics mordanted with alum, and various shades of olive with iron mordants. It is much used in calico-printing.

QUICKLIME. See LIME.

QUICKSILVER. See MERCURY.

QUILL. See PEN.

QUININE, a vegeto-alkali obtained from yellow bark, as *cinchonia* is from pale bark. [See BARK.] The valuable medicinal properties of the Peruvian barks are due to these vegeto-alkalis. They are associated in the bark with sulphuric and *kinic* acids. Pale bark, or *cinchona condaminea*, contains most cinchona; and yellow bark, or *C. cordifolia*, most quinia. Both are contained in *C. oblongifolia.*

There are various methods of preparing cinchonia and quinia. The simplest is to add a slight excess of hydrate of lime to a strong decoction of the ground bark in acidulated water; to wash the precipitate and boil it in alcohol. The solution filtered while hot deposits vegeto-alkali on cooling. When both bases are present they may be separated by converting them into sulphates, the salt of quinia being the less soluble of the two crystallizes first and may be separated.

Cinchonia $C_{20} H_{12} NO$, crystallizes in small, brilliant, transparent, four-sided prisms. It dissolves slightly in water, but readily in boiling alcohol; it has little taste, although its salts are excessively bitter. It acts as a powerful base, completely neutralizing acids and forming crystallizable salts. Quinia or quinine $C_{20} H_{12} NO_2$, resembles cinchonia in many particulars: but it does not crystallize so readily: it is more soluble in water and its taste is intensely bitter. Sulphate of quinine, as mentioned under BARK, is largely manufactured for medicinal use: it crystallizes in small white needles, and its solubility is increased by the addition of a small quantity of sulphuric acid.

The refuse or mother liquor of the quinine manufacturers contains *amorphous quinine*, also called *chinoidine* or *quinoidine.* It is a yellow, or brown resin-like mass, insoluble in water, but freely soluble in alcohol and ether, as also in dilute acids. It is said to be identical in composition with quinine; if so, it may bear to quinine the same relation that uncrystallizable syrup does to ordinary sugar, it being pro-

duced from quinine by the heat employed in the preparation.[1]

RADIATION. See HEAT.

RAILWAY. See ROAD.

RAIN-GAUGE. The quantity of rain which falls at different times and in different places is very variable, although the mean annual quantity is tolerably constant for the same locality. Instruments called *pluviometers* or *rain-gauges* have been contrived for measuring the quantity which falls on a given spot in a given time. The simplest form of rain-gauge is a funnel 3 or 4 inches high, Fig. 1803, the mouth having an area of 100 square inches, placed in a large bottle, and exposed in an open place to the weather. After each considerable fall of rain, the

Fig. 1803. *Fig.* 1804.

quantity of water collected in the bottle is to be measured by a glass jar, Fig. 1804, divided into inches and parts. In such a case the mouth of the funnel evidently represents a portion of ground; and the water collected and measured is the depth of rain which would cover the ground at and about the observed spot if the ground were horizontal, and the water could neither flow off nor sink into the soil. By noting down the quantity of rain which thus falls day by day and year by year, and taking the average of many years, the mean annual fall of rain is obtained for the particular place, and by extending these observations the mean annual fall of rain is obtained for a district or a kingdom.

A convenient form of rain-gauge consists of a funnel fixed to the top of a brass or copper cylinder, Fig. 1805, with a glass tube rising from near the bottom and graduated into inches and tenths of an inch. The water stands at the same height in the glass tube as in the cylinder and the height can be read off from the graduated scale. The cylinder and the tube are so constructed that the sum of the areas of their sections is a given part, such as a tenth of the area of the mouth of the funnel; so that each inch of water in the tube is equal to the tenth of an inch of water in the cylinder. A stopcock is added for drawing off the water from the cylinder after each observation.

Fig 1805.

Some years ago Mr. Phillips submitted to the British Association a rain-gauge constructed so as to show the quantity of rain from each of the four principal quarters of the horizon. Self-registering gauges are constructed on the principle explained under ANEMOMETER, Fig. 43.

The rain-gauge should be placed in an exposed situation, if possible at a distance from buildings and trees. The quantity of water in the gauge should be observed at least twice a day in rainy weather. A less frequent observation may lead to error in consequence of the rapid evaporation of water. The gauge should also be as near the surface of the ground as possible; for it appears that the gauge indicates different quantities of rain as falling in the same locality according to the different heights at which it is placed. Thus the annual depth of rain at the top of Westminster Abbey was found to be 12 $\frac{1}{10}$ inches; on the top of a house 16 feet lower down it was 18 $\frac{1}{10}$ inches; and on the ground in the garden of the house it was 22 $\frac{6}{10}$ inches.

Mr. Thom's rain-gauge consists of a cylinder 2 feet long and 7 inches in diameter, sunk in the earth until the mouth of the funnel, which receives the rain, is on a level with the surrounding ground. Into this cylinder is put a float with a graduated rod attached to it, the float and rod moving up and down as the water rises or falls in the cylinder. There is a thin brass bar fixed within the funnel, about $\frac{1}{2}$ inch under its mouth, with an aperture in the middle just large enough to allow the scale to move easily through it. The upper side of this cross-bar is brought to a fine edge, so as to cut but not obstruct the drops which may alight on it. There is an aperture also in the bottom of the funnel, through which the water must pass into the cylinder, and through which also the scale must move; but this aperture is not larger than will allow the scale to move through it freely. The cylinder is firmly fixed in a large flat stone, level with the surface of the ground. In the stone, a groove is cut round the gauge to guard it from receiving rain which may fall on the stone. The adjustment to zero is performed in the usual way.

Mr. James Johnston described a rain-gauge so constructed, that the receiving-funnel or orifice, at which the rain enters, is always kept at right angles to the falling rain. By the action of the wind on a large vane, the whole gauge is turned round on a pivot until the front of the gauge faces the wind, and by the action of the wind on another vane attached to the receiving-funnel, the mouth of the funnel is moved

(1) Fownes, "Manual of Chemistry." A full account of the methods of preparing cinchonia and quinia is given in the fifth volume of Dumas, Chimie appliquée, &c. Large quantities of the sulphate of quinine were formerly manufactured at Paris for medicinal use, but of late years the trade has been extended to other countries. Probably the largest makers in the world are Messrs. Zimmer of Frankfort, who supply the greater part of Russia, Austria, and Prussia, with this article. Messrs Howard and Kent of Stratford, are probably the largest manufacturers in Great Britain. The retail price of sulphate of quinine is about 12*s*. per ounce.

towards a perpendicular position, according to the strength of the wind. The receiving-funnel and vane attached to it are balanced with counterpoise weights in such a manner, that the wind, in moving them, has as much weight to remove from a perpendicular position, in proportion to their bulk, as it has when moving an ordinary sized drop of rain from the same position: by this means, the mouth of the gauge is kept at right angles to the falling rain.[1]

In the year 1844, Mr. Ronalds, in his Report on the Kew Observatory, described a Rain and Vapour-gauge which indicated a mean result arising from the quantity of water which may have fallen between any two given periods, minus the quantity of vapour which has arisen in the same time (and *vice versâ*) on and from a circular plane of one foot in diameter. A A, Fig. 1806, is a cylindrical vessel of zinc of the internal diameter of one foot; B is another cylindrical

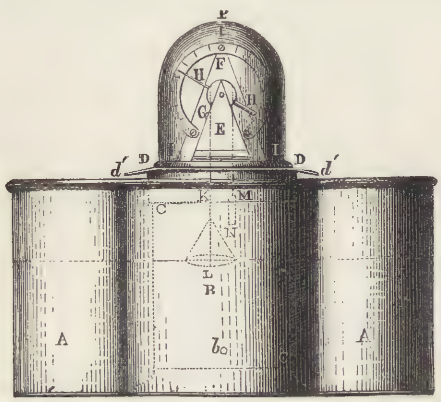


Fig. 1806.

vessel attached to A, and communicating with it by a small pipe *b*; C is a glass vessel standing in B, and having a small perforation near its foot; D D is a circular plate of brass firmly screwed to a cap C, and *d′ d′* is a copper plate, also attached to the cap of C; E and F are cocks fixed upon D, at a distance of about $\frac{3}{4}$ inch from each other; G is a pulley upon an arbor, running in centres opposite to each other in the supports E and F; the centres are jewelled, and the carefully-turned pivots of the arbor are of platinum; H is an index carried by G, and I I I is the scale screwed upon F; K is a silken thread passing round a groove in G, descending through a hole in D, and suspending a light copper-covered dish I; M is another silk thread passing in the contrary direction round another groove in G, and suspending a weight N, which is somewhat lighter; P is a glass shade placed upon D D. This arrangement is an application of the principle of the wheel barometer. If a quantity of water be poured into A, exactly sufficient to bring the index H to a given point, and if afterwards any addition be made to that quantity by means of rain, the index will point out the increase upon the multiplying scale I; or if any diminution of that quantity should be occasioned by evaporation, the loss will also be pointed out by the motion of the index in the contrary direction. The index is brought to zero every day at sunset by the addition to or subtraction of water in A, and the mean results of deposition and evaporation for the preceding 24 hours are observed. A small reservoir is placed near with a pipe and cock for supplying water. The instrument is fixed upon a stand at about 2 feet above the leaden roof of the observatory. It would, however, be more properly situated if the cylinders A and B were sunk in the neighbouring earth. The use of the plate *d′ d′*, and of the glass shade P, is to exclude rain from B, and for protection. If it were required to be used as a rain-gauge only, a funnel might be fitted upon A; if for a vapour-gauge only, the whole might be protected from rain by a roof placed some feet above it.

(1) British Association Report, vol. x.

RAISED WORKS IN METAL. The malleability of several of the ductile metals and alloys is illustrated in a remarkable manner in the production of various well-known articles, such as tea-pots, coffee-pots, covers of cups and vessels, the bell mouths of musical instruments, extinguishers, thimbles, &c. Circular works in thin metal are rapidly formed on a turning lathe, by the process of what is called "spinning or burnishing to form," or by raising by the hammer, or pressing between dies. Fig. 1807 will illustrate the method of spinning the body of a Britannia metal tea-pot from a complete disk of metal. The disk *d d*

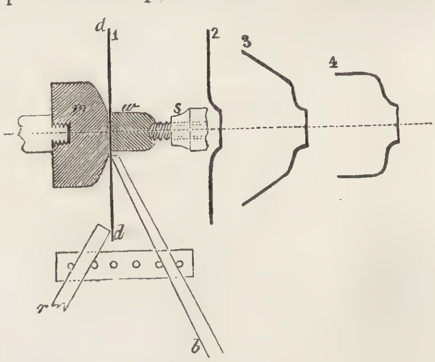


Fig. 1807.

is pinched by the fixed centre screw *s* of the lathe, between two flat surfaces of wood *m w*, one of which *m*, is a mould or chuck turned to the form of the lower part of the tea-pot; by which arrangement *m*, *d d*, and *w*, revolve with the mandrel. A burnisher *b*, resting against a pin in the lathe-rest is now applied near the centre of the metal, and a wooden rod *r* being held on the opposite side to support the edge, the metal is rapidly bent or swaged through the successive forms 1, 2, 3, 4, so as to fit close against the curved face of the block and to extend up its cylindrical edge. The mould *m* is now removed, and in its place is screwed on a cylindrical block *c*, Fig. 1808, of the diameter of the intended aperture or mouth of the tea-pot. One of the numerous forms of burnishers employed in

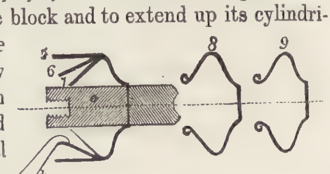


Fig. 1808.

this kind of work is selected; its surface is slightly greased, and is applied in conjunction with the hooked stick *h*, to force the metal gradually inwards, as shown at 5, 6, 7, and also to curl up the hollow bead which stiffens the mouth of the finished vessel 9. In some cases the moulds *m* are made of the exact shape of the vessel to be turned: each mould is made up of a number of pieces, each piece smaller than the central opening; so that like the parts of a hat-block [see HAT, Fig. 1130], or of a boot-tree, on taking out the central block all the other parts are easily released. It is important during the spinning to keep the edge exactly concentric and free from notches: should these occur, the edge is to be touched with the turning tool. "The operation," says Mr. Holtzapffel is very pretty and expeditious, and resembles the manipulation of the potter, who forms a bottle or vase with a close mouth in a manner completely analogous, although the yielding nature of his material requires the fingers alone, and neither the mould, stick, nor burnisher."[1]

The second method of raising works is by means of the hammer, by the application of circles of blows applied much in the same order as the burnisher, which acts by the gradual and continued pressure on one circle at a time. The metal disk to be raised must be so selected as to size and thickness that it shall exactly suffice for the production of the article, leaving no excess of metal to be cut off, nor deficiency to be supplied; and the blows of the hammer must be so managed as to direction and intensity that the finished work shall be of uniform thickness throughout. Thus, a hollow ball 6 inches in diameter is made up of two circular pieces of copper each 7½ inches in diameter: the circumference of the disk measures 22½ inches, and this becomes contracted to 18 inches, or the circumference of the ball, while the original diameter of the disk, 7½ inches, has become extended to 9 inches, or the girth of the hemisphere. This double change of dimensions is still more strikingly illustrated in the spinning of the tea-pot, Fig. 1807, the disk for which was about 1 foot in diameter; this is contracted to 2 or 3 inches at the mouth. In the use of the hammer for works of this kind, care must be taken to distinguish between *opposed* or *solid* blows, which have the effect of stretching or thinning the metal; and *unopposed* or *hollow* blows, which tend not to thin the metal but rather to bend and even to thicken it. Minute directions on these points are given in Mr. Holtzapffel's work.

One of the most remarkable examples of raised works is the ball and cross of St. Paul's Cathedral, London, erected in 1821. The old ball consisted of 16 pieces riveted together: the present ball is of the same diameter, viz. 6 feet; this was raised in two pieces only, and may be regarded as a fine example of the coppersmith's art. The metal for the ball was first thinned and partly formed under the tilt-hammer at the copper mills, and sunk in a concave bed; the raising was effected with hammers not much larger than usual, and the two parts were riveted together in their place, the joint being concealed by the ornamental band. Most of the work of the cross and ball is hammered up; the consoles beneath the ball are of cast gun-metal. The whole structure is 29 feet high, and the weight of copper 3¼ tons. The ball and cross are strengthened by an inner framing of copper and wrought iron bars, stays, bolts, and nuts, extending through the arms and downwards into the building, thus adding about 2 tons of iron to the load of copper. 38 oz. of gold were consumed in the gilding. Sugar-pans, stills, &c., are made of very large size, on the same principle.

Works, such as jelly-moulds, in which the raising is very considerable, are produced by the hammer; but works in less relief, required in considerable numbers, are produced by means of dies. For the best works both the top and bottom dies are usually of hardened steel, but in some cases the bottom die is of cast-iron or hard brass: in many cases, the top die is also of lead, this metal being preferred from the facility with which it assumes the required shape, The method of producing figures in relief on buttons by raising and letting fall a succession of *forces*, is an example of this kind of work [see BUTTON, Fig. 393]; we are, however, now referring to larger works than buttons, in which cases the sheet of metal to be raised undergoes the same bendings and stretchings between the dies as if it were worked by the hammer, and unless gradually produced the metal will be cut and rent. This gradual action is brought about by placing a number of sheets of metal between the two parts of the die, and after every blow one piece is removed from the bottom, and a fresh plate added at the top: in this way the plates descend and gradually accommodate themselves to the figure of the die. The pieces are finished by being struck singly between dies which exactly correspond. In thus gradually bringing the plates into the required shape, they may require annealing from time to time. Thimbles are raised at 5 or 6 blows between as many pairs of conical dies, gradually increasing in height, but in passing from one pair of dies to another the metal requires to be annealed.

The art of stamping and shaping sheet metal was made the subject of a patent granted to Mr. T. Foxall Griffith of Birmingham, Feb. 3, 1846. By the methods here employed, works with lofty and perpendicular sides, such as jelly-moulds, are produced by the alternation of stamping and spinning. By a former patent, the sheet metal, having been raised as far as possible in dies by stamping, the shaping was completed by burnishing to form. "In shaping sheet metal by stamping, as heretofore practised, the sides of the articles depend materially for the height of the raising on the stretching or extending of the metal; and, to this end, the metal at the outer circumference is supported throughout the process of stamping by a projecting flanch, which rests horizontally on the upper surface of the dies, such flanch being progressively reduced, and the metal thereof stretched or extended, so that,

(1) In the first volume of the "Mechanical Manipulation" will be found a very full and highly instructive chapter on "Works in sheet metal made by raising."

from the bottom to the upper edge, the thickness of the metal is brought thinner and thinner, which is objectionable. At the same time, owing to the severe treatment to which the sheet metal is thus subjected, it requires to be more often annealed, in order to prevent its suffering injury by the successive processes of stamping; and such is the extent to which the metal is stretched or extended by raising, according to the old practice, that the disk, or blank of metal employed for raising a vessel of a few inches diameter to a considerable extent, is only about $\frac{3}{4}$-inch larger in diameter than the finished vessel raised therefrom by stamping. Whereas, according to my invention, the blank or disk of sheet metal used for making any particular article when the sides thereof are upright, is of a diameter of about the diameter of the vessel or article added to the depth of the vessel: thus, supposing the vessel or article produced by stamping in a die be 6 inches in diameter and 3 inches deep, then the die or blank of sheet metal would

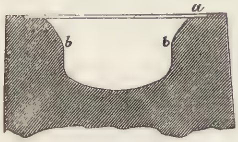


Fig. 1809.

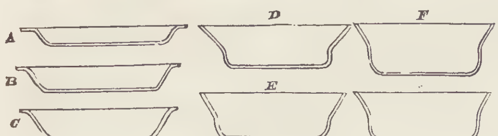


Fig. 1810.

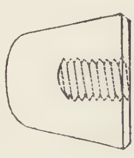


Fig. 1811.

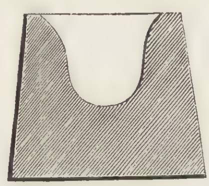


Fig. 1812.


Fig. 1813.

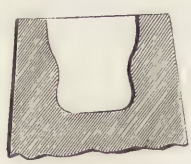


Fig. 1814.

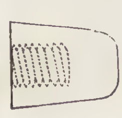


Fig. 1815.

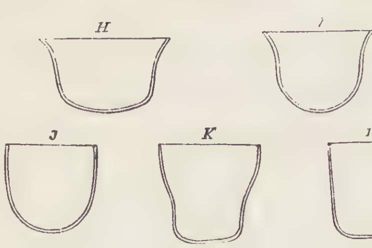


Fig. 1816.

be about 9 inches diameter, and the article when stamped therefrom, if it be cut through the sides and bottom, all parts would be found as nearly as may be of the same thickness, and that thickness the thickness of the original sheet metal."

The vertical sections, marked A to G, Fig. 1810, represent the several forms given to the sheet of metal *a a*, Fig. 1809, by employing a die such as that shown in the same figure, with a second point of bearing at *b b*; the successive *forces* or top dies, that are employed, being so shaped as to bear only on the bottom of the vessel as far as the edge *b b*, and not over the sloping sides, the effect of which is to make the edge *b b* perform the office of a draw-plate, such as would be used for drawing cylindrical tubes. Having been progressively stamped to the contour of G, the work is burnished to form on a chuck, Fig. 1811. The work is again stamped in the second die, Fig. 1812, then burnished on the second chuck, Fig. 1813; struck in a third die, Fig. 1814, and then burnished on a third chuck, Fig. 1815, in order to make the metal proceed through the forms H to L, Fig. 1616. The work is occasionally annealed as required.

Fluted works, such as M N Fig. 1818, are first raised nearly as cylinders with bottoms to the shape of L by the processes just noticed: the burnishing to form is then discontinued. The flutes are gradually developed by means of 2 or more pairs of dies and forces, Fig. 1817. In the first pair of tools for the object N the flutes are shallow, and the die is a little bell-mouthed: in the second pair the flutes

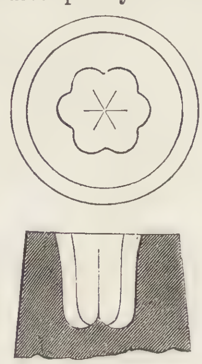


Fig. 1817.

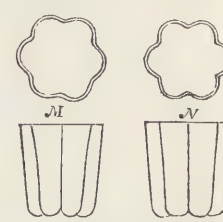


Fig. 1818.

are of the full depth, and as, from the sides being almost perpendicular, or exactly counterparts of the burnished object N, the piece, when struck, holds

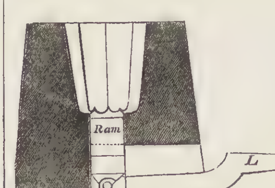


Fig. 1819.

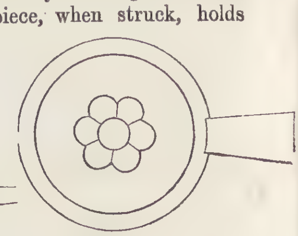


Fig. 1820.

fast in the die, the latter is perforated, and has a central rammer, Fig. 1819, which is raised by a side lever L to force the finished work out of the die.

That the metal after the raising should be of uniform thickness throughout, is thus explained in the case of the cylindrical vessel already referred to. If the disk, 9 inches in diameter, by stamping in a die 6 inches in diameter, could have its margin folded up without puckering, it would have a rim of $1\frac{1}{2}$-inch high, the upper edge being of twice the primary thickness; but the stretching from the dies causes the height of the sides to become 3 inches, and therefore

the tapering thickness actually produced is gradually drawn out, as in tube-drawing, to form the increased height.

So successful is the improved method of raising, that sheet-iron, which is much less tractable than copper and brass, may be raised. The scaling of the surface of the iron during the annealing was at first a difficulty, but this was obviated by annealing after the manner adopted for malleable iron castings, [see ANNEALING,] the annealing mixture preferred being 1 part of pulverized iron ore added to 8 parts of coke or lime, preference being given to that iron ore which has been once used for annealing cast-iron. Thus, by the combined processes of stamping and burnishing to form and annealing, extinguishers can be raised from disks of sheet-iron: they are of course without a seam. The method of stamping with dies having the bevelled mouth and shoulder *b b*, Fig. 1809, allows vessels to be raised much higher than by any other method of stamping, even when burnishing to form is not employed in conjunction with stamping.

The various ornamental details of raised work, such as escutcheons, concave and convex flutes, are usually added after the vessel or article has received its gene-

Fig. 1821.

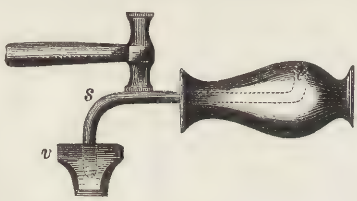


Fig. 1822.

ral form by one or more of the processes described. If, from the shape of the work, swage tools, such as those represented in Fig. 1821, cannot be employed for raising the projecting parts, they are *snarled up* by means of a *snarling-iron*, *s*, Fig. 1822. One end of this iron is secured between the jaws of a tail-vice *v*, and the other end *e* is turned up so as to reach any part of the interior of a vessel. The work is held firmly in the two hands with the part to be raised or *set-out* exactly over the end *e:* the snarling-iron is then struck by an assistant with a hammer at *h*, and the reaction gives a blow within the vessel which throws out the metal in the form of the end of the tool. After the flutes or other ornaments have been snarled-up, the vessel or other object is filled with a melted composition of pitch and brick-dust, or some similar mixture, which, from its adhesive and yielding nature, forms an excellent support in the operation of *chasing*, leaving both hands at liberty, one to hold the punch and the other the hammer. The punches or chasing tools, *t*, are counterpart forms of the several raised parts, and with them the snarled-up parts are corrected, some portions of the metal being driven in, while those around rise up from the displacement and reaction of the pitch. The lower portion of the work is preserved from injury by being supported on a sand-bag *s*, Fig. 1823.

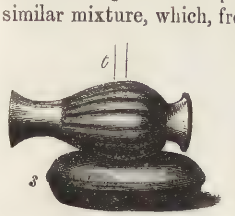


Fig. 1823.

RAISINS. In the south of Europe and in Egypt, &c. grapes are allowed to ripen and dry upon the vine so as to form raisins. The sweet fleshy grapes which grow upon the sunny sheltered slopes of hills are preferred. When the fruit is ripe, the grapes are thinned and the vine is stripped of its leaves. The sun then completes the saccharification and drives off the superfluous water. When the bunches are plucked they are cleaned, dipped for a few seconds in a boiling lye of wood-ashes and quicklime; the wrinkled fruit is then drained and dried, exposed to the sun upon hurdles for 14 or 15 days. The finest *sun* raisins are the plumpest bunches left fully to ripen upon the vine, after their stalks have been cut half through. An inferior kind of raisins is prepared by drying the grapes in an oven.

In the year ending 5th Jan. 1853, 261,824 cwt. of raisins were imported into the United Kingdom, of which quantity 208,801 cwt. were retained for home consumption. The import duty is 15*s*. per cwt. from foreign countries, and 7*s*. 6*d*. per cwt. from British possessions.

RAM. See HYDROSTATICS and HYDRODYNAMICS.

RAPE-OIL. The seeds of *Brassica rapa* and *B. napus* are valuable for the large quantity of oil which they yield by expression. [See OILS and FATS.] *B. rapa* yields the largest quantity of oil. *B. campestris* yields a superior oil known in France as *Colza* oil. Rape-oil is thick, of a yellow colour, and with a peculiar taste and smell; it concretes into a yellow mass at about 28°. Its specific gravity is 0·9167. It is used in the preparation of woollen goods and of some kinds of leather. It is much used in France for burning in lamps. Colza-oil may be used without purification, and it is largely employed in lighthouse lamps. [See LIGHTHOUSE.] The common kind of oil is purified by being agitated with a 200th part of sulphuric acid, left to repose for 24 hours, when two-thirds of its bulk of water at 165° are added, and the mixture stirred until it becomes milky. It is then kept for 2 or 3 weeks in a room heated to 80°, when it becomes clear by the deposition of a dark coloured sediment. It is lastly filtered by being drawn off into vats the bottoms of which are pierced with holes stuffed with filaments of carded wool or cotton. Having passed through this filter the oil is fit for use. The acid may be removed by the addition of powdered chalk.

RAREFACTION. See AIR—EVAPORATION—ICE.

RASP. See FILE.

RATAFIA. Certain liqueurs, such as *noyau, curaçoa*, &c., are termed *ratafias* from the custom of drinking them at the *ratification* of an agreement. (*Ratum* and *fio* to make firm.)

RATCHET-LEVER. See WHEEL.

RAY. See LIGHT.

RAZOR. See CUTLERY.

REALGAR is the red sulphuret of arsenic As S_2. See ARSENIC.

RECEIVER. See DISTILLATION.

RECOIL ESCAPEMENT. See HOROLOGY, Fig. 1163.

RECTIFICATION. See DISTILLATION.

RED LEAD. See LEAD.

REED. See WEAVING.

REFINING or PARTING. See ASSAYING—SILVER.

REFLECTION and REFRACTION. See LIGHT.

REFRIGERATION. See BEER—ICE—EVAPORATION.

REGULUS. See ANTIMONY, vol. i. p. 59, where this term is explained.

REISNER-WORK. See BUHL-WORK.

RESINS. Resinous substances are found in greater or less abundance in most plants. Many of them exude naturally from fissures in the bark or in the wood, or they are obtained from incisions made in certain trees and shrubs. As they exude they are commonly mixed with an essential oil, which either evaporates on coming in contact with the air, or is resinified by the action of oxygen. Such mixtures of volatile or essential oil with resins are sometimes called *balsams* [see BALSAM]. When gum is mixed with resins another class of substances is produced, called *gum-resins*. [See GUM-RESINS.]

The resins when pure and free from essential oil have no odour except when rubbed or heated. Their colours are pale yellow or brown; they are good insulators, and become electric by friction. Most of them are heavier than water and insoluble in that fluid; they have little or no taste, but those which have distinctive flavours derive them from minute portions of some non-resinous body. They are usually softened or even fused by being boiled in water, and some of them in such a case pass into hydrates. They are inflammable, burning in the air with a sooty flame, and yielding by dry distillation volatile liquids and inflammable gases. [See GAS.]

The natural resins are usually composed of two or more resinous substances, which may be separated by the action of alcohol, in which most resins are soluble. They are also mostly soluble in ether, in sulphuret of carbon and in the fat and volatile oils. Alcoholic solutions of many of the resins act the part of feeble acids, reddening litmus paper, and combining with and neutralizing acids. These compounds are termed *resinates* or *resin-soaps*, and are distinguished from *oil-soaps* by not forming a gelatinous emulsion when concentrated, and by not being separable from water by the addition of common salt: they are, however, detergent and form a lather like common soap. [See SOAP.]

Other resins are indifferent either as an acid or a base, but there are a few which are regarded as *basic*. The resins are thrown down from their alcoholic solutions by the addition of water, the white pulverulent or curdy precipitate forming the *magistery* of the old chemists. The alcoholic solution of the acid resins is not precipitated by ammonia; but the precipitate thrown down by the addition of water is soluble in solution of ammonia. The alcoholic solution of the indifferent resins is precipitated by ammonia. The acid resins may also be distinguished by the crystalline precipitate produced by the addition of their ammonio-chloride solutions to nitrate of silver.

Some of the resins dissolve in sulphuric acid without decomposition in the cold, and they are precipitated by the addition of water; but if heat be applied sulphurous and carbonic acids are disengaged, and a carbonaceous mass is obtained mingled with another substance which has been improperly named *artificial tannine*. The action of nitric acid upon resins leads to the formation of various new products. Acetic acid dissolves many of the resins, as does also muriatic when concentrated.

The resins have been considered as oxides of definite hydrocarbons; but their analysis is very imperfect, and will be further noticed under TURPENTINE.

RETORT, a vessel of glass, earthenware, porcelain, clay, iron, &c. in which some kind of distillation is carried on. Numerous examples of retorts are given in the course of this work. See GAS—NITRIC-ACID, &c.

REVERBERATORY FURNACE. A furnace so constructed that the flame shall be reflected or reverberated upon the bed or sole over which the material to be operated on by the flame is spread. See COPPER—IRON—LEAD, &c.

RHODIUM. See INTRODUCTORY ESSAY, page c,—also, PLATINUM.

RHUBARB, the root of one of the species of *Rheum*, a genus of plants of the natural family of Polygonaceæ. Although rhubarb has been in use for centuries, the particular species of rheum which yields it is not known, in consequence of the best, or *Turkey rhubarb*, being obtained only by the Russians at Kiachta from the Chinese. There are six well-marked varieties in commerce, viz. the *Russian* or *Turkey*, the *Dutch-trimmed*, the *Chinese*, the *Himalayan*, the *English*, and the *French*. The following description refers to the first variety, also called *Muscovite*, *Bokharian*, or *Siberian* rhubarb. The pieces are of various forms, cylindrical, spherical, flat, or irregular, from 2 to 3 inches long, 1 to 3 broad, and 1 to 3 thick. The smaller pieces are preferred, the larger ones being employed for powdering. The holes observed in the pieces were originally made for suspending them while drying, or for ascertaining their quality. Other perforations are referred to the ravages of a small beetle. The pieces are covered with a bright yellow-coloured powder, the result of friction during carriage, or from the process of *rouncing* or shaking them up in a bag with powdered rhubarb. The odour is strong and peculiar: when chewed it feels gritty from the presence of numerous *raphides* or crystals of oxalate of lime: it imparts a bright yellow colour to the saliva, and has a bitter, slightly astringent taste. When fresh cut, the root has a reddish-yellow hue, with white lines interspersed. The powder is of a bright yellow colour verging on red, but it is usually adulterated by admixture with an inferior kind. Black and worthless pieces of rhubarb are sometimes disguised by means of yellow ochre; and inferior rhubarb, or roots cut to resemble the genuine article, are some-

times sprinkled over with powdered turmeric, or dyed therewith.

Many analyses of rhubarb have been made with the view to ascertain the source of its medical activity, which has been successively ascribed to a bitter principle, to an organic basis, to an acid, to a gum, to a resin, and to a colouring matter. Some later researches by Schlossberger and Döpping, show that there are three resinoid substances in rhubarb, together with extractive matter, and the medical virtues of the root are ascribed not to any one principle, but to a mixture of several, amongst which are tannin and gallic acid.

RIBBON, or RIBAND. See WEAVING.

RICE is a valuable cereal grass, *Oryza sativa*, extensively cultivated in India, China, and most eastern countries; in the West Indies, Central America, and the United States, and in some of the southern countries of Europe. It occupies the same place in intertropical regions as wheat in the warmer parts of Europe, and oats and rye in the more northern. The rice plant appears to be a native of India, where it is cultivated largely, forming as it does the chief portion of the food of the inhabitants. The varieties of rice are innumerable; 40 or 50 at least being described. The rice fields require a large quantity of water, which is supplied by rain or by irrigation either from rivers or banks. The best rice fields are extensive open plains intersected by large rivers, so as to be annually overflowed by the inundations. Most of the rice lands of India, however, depend on the rains only. The different varieties of rice are divided by Dr. Roxburgh into two kinds; one, named *Poonas* or *Asoo*, is sown thick in June or July, and transplanted in about 40 days, when the plants are from 9 to 18 inches high: the fields are then kept constantly wet; they are more or less flooded, as some sorts require very little water, others a great deal. When the grain is ripe, the water is drained off, and the crop cut down with the sickle: it is either stacked or trod out by cattle. The grain is preserved in pits dug in high ground, and lined with the rice straw. The straw is stacked for feeding cattle during the hot season. The second division of cultivated rice is named *Pedder Worloo.* Rice is also divided according to the seasons in which it is reaped, into that which ripens in the hot weather of spring, in the summer, or in the winter.

Carolina rice is grown in the marshy grounds of North and South Carolina. The grains are shorter, broader, and boil softer than the *Patna* or best Indian kind known in this country.

Rice in its natural state, or before it is separated from the husk, is named *paddy.* The husk adheres very closely, and should be separated without breaking the grain. In India and China the operation is performed by beating the grain in a kind of rude mortar of stone or earthenware with a conical stone attached to a lever worked by the hand or foot, or several such levers are worked by arms projecting from the axis of a water-wheel. A preferable mode is to employ a mill in which the stones are sufficiently removed to detach the shell and not crush the grain. A sifting and winnowing apparatus is attached to each pair of stones. When the husk is removed the grain is passed through a *whitening machine,* for the purpose of removing the inner cuticle or red skin. This machine resembles that described under BARLEY, Figs, 92, 93, and 94. The rapid motion of the grains through the machine and the friction to which they are exposed, cause them to swell and thus to split the red skin, which flies off in dust through the perforated revolving case.

The import duty on cleaned rice is 6*s.* per cwt. from foreign countries, and 6*d.* from British possessions; but when rough or in the husk (paddy) the duty is 7*s.* per quarter for foreign, and 1*d.* per quarter for British. These considerable differences in the amount of duty have led to the practice of importing paddy and cleaning it in this country. The cleaning apparatus mostly consists of millstones for breaking the husk, or one millstone and one block of wood of similar shape, and the dark pellicle is got rid of by passing the grain between flat wooden surfaces covered with sheepskin, so as to produce an effect similar to that of rubbing the grain between the palms of the hands. A machine first used in the United States consists of a long hollow cylinder of wood with bars projecting from its inner surface: an internal cylinder is also furnished with bars alternating with the former. The outer cylinder is made to revolve slowly in one direction, and the inner cylinder rapidly in the other direction. The machine is in an inclined position, and is supplied with paddy from a hopper at the highest part: the friction of the arms causes the husk to separate, which is blown away by a current of air as it falls out of the cylinder, while the rice is collected in a bin.

The following analysis of rice is by Braconnot:—

	Carolina	Piedmont.
Water	5.0	7.0
Husk	4.8	4.8
Gluten	3.6	3.6
Starch	85.07	83.8
Sugar	0.3	0.05
Gum	0.7	0.1
Oil	0.13	0.25
Phosphates	0.4	0.4
	100.0	100.0

RICE GLUE, or JAPANESE CEMENT, is made by mixing rice flour intimately with cold water, and boiling the mixture. It is white, and dries nearly transparent, hence its use in making many articles in paper. When made with a smaller quantity of water, models, busts, &c., may be formed of it.

RICE PAPER, a name applied to a delicate vegetable film imported from China in small square pieces of various colours, and used in the manufacture of artificial flowers and fancy articles, and also as a drawing paper for delineating richly-coloured insects or flowers. This substance is said to be a membrane of the bread-fruit-tree, and although it resembles an artificial production, yet on examination by the microscope it is found to consist of "long hexagonal cells, whose length is parallel to the surface of the film;

that these cells are filled with air when the film is in its usual state; and that from this circumstance it derives that peculiar softness which renders it so well adapted for the purposes to which it is applied."[1]

RIFFLER—See FILE.

RIFLE—See GUN.

RINSING MACHINE—See CALICO PRINTING, Fig. 415.

RIVETTING is the art of joining metal plates together, and the method of doing so varies with the article and the uses which it is intended to serve. Fig. 1824 represents the joint commonly used in strong iron plate and copper works, boilers, &c. The

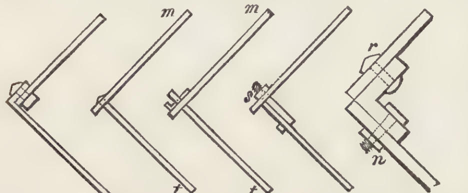


Fig. 1824. *Fig.* 1825. *Fig.* 1826. *Fig.* 1827. *Fig.* 1828.

edge of one of the sheets of metal having been turned up, the other edge is placed in the angle, a rivet is inserted at each end to hold the plates in position, and the other holes are then punched through the two thicknesses with the punch Fig. 1829 on a block of lead. The head of the rivet is put within, the metal is flattened around it by placing the small hole of the *rivetting set* or punch for the holes of rivets, Fig. 1830, over the pin of the rivet, and giving a blow: the rivet is then clenched, and it is finished to a circular form by the concave hollow in another rivetting set. If the work does not admit it being laid on an anvil or stake, a heavy hammer is held against the head of the rivet to receive the blow. In large works the holes are punched before rivetting. In Figs. 1825, 1826, the plates *m m* are punched with long mortises, and *t t* are formed into tenons which are inserted and rivetted. In Fig. 1826 the tenons have transverse keys to enable the parts to be separated. In Fig. 1827 one plate makes a butt-joint with the other, and is fixed by screw-bolts *s*, or by L-shaped rivets. This method is common for cast-iron plates as in stove work. Fig. 1828 shows the method adopted for strong vessels, such as steam boilers, in which the plates of wrought-iron are connected by angle iron rolled for the purpose. "The rivet-holes are punched in all the 4 edges by powerful punching engines furnished with travelling stages and racks, which ensure the holes being in line, and equidistant, so that the several parts, when brought together, may exactly correspond. The rivet *r*, which may be compared to a short stout nail, is made red-hot, and handed by a boy to the man within the boiler, who drives it into the hole: he then holds a heavy hammer against its head, whilst 2 men quickly clench or burr it up from without: between the hammering and the contracting of the metal in cooling, the edges are brought together into most intimate and powerful contact. Bolts and nuts *n* may be used to allow the removal of any part, as the man-hole of the boiler. For the curved parts of the boilers, the angle iron is bent into corresponding sweeps, and for the corners of square boilers the angle iron is welded together to form the 3 tails for the respective angles or edges which constitute the solid corner: this, when well done, is no mean specimen of welding."[2]

Fig. 1829. *Fig.* 1830.

In our article BRIDGE, Sec. VI. various forms of rivets are shown.—See Figs. 335, 336, and 347 to 353. Much of the rivetting for the Britannia Tubular Bridge was done by Mr. Fairbairn's *rivetting machine.*

ROADS and RAILROADS. A road may be defined as an artificial floor so constructed as to present a straight, level, smooth and hard surface, connecting different parts of a country with each other, and allowing men and animals to travel over it with facility and despatch. The construction of roads marks the first change of every nation in emerging from a state of poverty and barbarism; just as improved means of intercommunication marks their advance in wealth and intelligence; for it is found that in proportion as roads are level and hard are the facilities of moving over them, and that these facilities greatly diminish the expenses of travelling and the cost of conveying goods; and the saving thus effected is applied to increased production or to other improvements.

The importance of roads was fully admitted by the nations of antiquity, as appears from the testimony of their historians. Paved roads are said to have been first constructed by the Carthaginians; but the Romans were the first people to carry out a system of roads on a most extensive scale, and with such solidity of construction that many of them remain in use to the present day. In Italy alone, the ancient Romans constructed several thousand miles of road, and they also formed roads in every country of their vast empire. Although the primary object of these vast public works was to facilitate the movements of the military, yet they were productive of great benefit to the countries through which they passed. The Roman road-makers connected different stations by means of straight lines, overcoming natural obstacles with the skill of a modern railway engineer, making large excavations, building numerous bridges, and driving tunnels often of considerable length. And the solidity of the construction was equal to the boldness of design: these roads have sustained the traffic of 2,000 years without material injury, thus proving the wisdom of the method of securing a firm foundation. This was done where necessary by ramming the ground with smooth stones, fragments of brick, &c. On this was constructed a pavement of large stones firmly set in cement. The stones were occasionally squared, but were usually of irregular shapes, accurately fitting. Many kinds of stone were used; but basalt was pre-

(1) Brewster, Edinburgh Journal of Science, vol. ii.

(2) Holtzapffel, Mechanical Manipulation, vol. i. chapter xviii., where other examples of welded joints are given.

ferred where it could be procured, even when good materials might be had at less labour and expense. If large blocks of stone could not be had, small stones of hard quality were cemented together with lime, so as to form a sort of concrete to the depth of several feet. Roman roads were generally raised above the surface of the ground, and they had frequently two carriage tracks separated by a raised footpath in the centre.

In Italy the Roman system of road-making has been partially followed, especially in city pavements. In Britain the Roman model was not followed, so that until within quite modern times, the art of road-making was in a most imperfect condition. The old roads consisted of paths or trackways, winding about so as to avoid very hilly or marshy ground, and also for the purpose of crossing rivers at certain fordable points. In general, however, a path over a hill was preferred to one round its base, on account of the firmer ground afforded by the former. The roads, such as they were, were supported by parish and statute labour, which being a voluntary service on the one hand, and a compulsory one on the other, was given grudgingly, and was therefore ineffectual. It was not until the system of maintaining roads by means of tolls was admitted to be just and practicable, that roads began to improve. Turnpikes were introduced soon after the Restoration, but they were so obnoxious to the popular mind that they produced but little result. In the reign of George II. an act was passed declaring it to be felony to pull down a toll-bar: but as the law could not make the public appreciate the value of toll-bars, roads continued almost in their ancient condition as late as 1752—4, when the traveller seldom saw a turnpike for 200 miles after leaving the vicinity of London. But at length the general spirit of improvement which resulted from a free government and a free printing-press had its effect in improving roads; for in the 14 years from 1760 to 1774 not fewer than 452 turnpike acts were passed, and from that period the number increased every year, so that long before the railway system came into operation not less than 23,000 miles of turnpike road had been constructed in this country.

It would naturally be expected that as roads multiplied, the principles of their construction would be investigated. The subject was indeed much discussed, but not until the employment of Telford and other skilful engineers, on the Highland and Holyhead roads, was a sound knowledge of the art of road-making established. Upwards of 900 miles of road were made or improved under the Highland Road Commissioners, and in 1815 the Holyhead road improvements were commenced under a Government Commission.[1]

(1) The work in which Telford's principles of road-making are carefully expounded is Sir Henry Parnell's "Treatise on Roads," 2d edition, 1838. We have to express our acknowledgments to this valuable work in the preparation of this article. Our illustrations are mostly from the Folio Atlas of Plates which accompanies the "Life of Telford."

The two great rival road-makers, who for a long time engaged public attention, each with his own system, were Telford and M'Adam. Telford required that every road should be laid down on a hard, solid, carefully-prepared foundation. M'Adam expressly says: "I should not care whether the substratum were soft or hard: I should rather prefer a soft one to a hard one." Telford saw that the roads of the United Kingdom were defective; 1, because it was the custom to mix a large quantity of earth with the materials which formed the crust of the road; 2, because this crust was too thin; 3, because it rested on an elastic substratum. M'Adam admitted the first objection, but practically denied it by constructing his road on a soft bed: we must, however, assign to him the merit of being the first to persuade the trustees of turnpikes to set about improving their roads, by teaching them how to prepare the materials; to keep the surface of the road free from ruts by continually raking and scraping it.

A road destined for much traffic requires to be laid out and constructed with greater care, and even on different principles, than a road on which the traffic is but small. A road of earth put into a regular form will answer for a park drive. The same, with a coating of gravel, will do for light carts and other carriages. A road with 10 or 12 inches of broken stones laid on the natural soil, will answer where the traffic is not considerable; but very great traffic requires a road to be as solid and hard as possible, to allow carriages to be drawn on it with as small an expenditure of tractive power as possible, an object which all road-makers ought to have in view.

The enumeration of roads, in the order just indicated, will therefore be as follows:—1, a road of earth put into a regular form; 2, a road of gravel laid on the natural soil; 3, a road with broken stones laid on the natural soil; 4, a road with a foundation of rubble stones, and a surface of broken stones or gravel; 5, a road with a foundation of pavement, and a surface of broken stones; 6, a road, of which the surface is partly paved, and partly made, with broken stones or other materials; 7, paved roads; 8, iron railways. Our attention will be chiefly occupied with the last 3 varieties. And although the general mode of travelling, now in use, is by railroad, it must not be supposed that the construction of the common road has ceased to be an object of great importance. There are a vast number of localities where the common road alone can be employed, and the railroad itself depends for much of its utility and success upon its accessibility by means of common roads.

The designing of a line of road requires much knowledge and deliberation. It is always prudent to survey several different lines, and afterwards decide on that in which the desirable qualities preponderate. The surveys should be neatly and accurately protracted and laid down on good paper, on a scale of 66 yards to an inch for the ground plan, and of 30 feet to an inch for the vertical section. The map should be correctly shaded, so as to exhibit a true representation of the country. The vertical section should show the

nature of the soil and of the different strata as ascertained by boring, in order to be able to determine and calculate at what inclination the slopes in the cuttings and embankments will stand. The system recently adopted of showing upon plans the levels of the ground by means of *contour-lines*,[1] is of great use, not only in the selection of roads, but in the drainage of towns, the supply of water, &c. There should also be noted down in the plan the existence of gravel-pits, stone-quarries, &c. near the line; and in crossing rivers the height of the greatest floods should be marked. These and many other points must be attended to, to enable the engineer to approach as closely as possible to the ideal of a road, *i.e.* a perfectly straight and level surface, and perfectly smooth and hard. Of course he is very far from attaining this perfection in practice, but it will be found that the best road which can be had is that which makes the best compromise of the deviations from perfection. The best road between two points is that which is the shortest, the most level, and the cheapest of execution. But this general rule may admit of qualification, for certain deviations may be rendered necessary by natural obstructions from hills, valleys, and rivers, by the amount of traffic, the cost of repair, and the necessity for taking in certain towns or villages in the line of road.

In laying out a road in a hilly country, the spirit-level must be used in order to show the proper line of road to be selected. [See LEVELLING.] The general rule in surveys is to preserve the straight line, except when it is necessary to gain the required rate of inclination without expensive excavations or embankments. An inclination or *gradient* of 1 in 35 is found by experience to be just such as will admit of horses being driven in a stage-coach with perfect safety when descending as fast as they can trot. Any rate of inclination greater than this will very much increase the labour of horses in ascending hills: and in descending, the horses would have to restrain the carriage from descending with accelerated velocity, or a drag would have to be put on the wheel for the purpose of increasing the friction. The drag, however, does so much injury to the surface of the road, that it is in no case desirable to employ it, unless the safety of the vehicle render it necessary.

With respect to the width of roads, those between towns of any importance, or where the traffic is considerable, should not be less than 30 feet, besides a footpath of 6 feet. Even a greater width than this will be advantageous near large towns and cities. Moreover, a wide road wears better than a narrow one, for in the latter case the traffic is more or less confined to one track, while in the former it is spread more equally over the surface. A wide road is also kept in a drier state than a narrow one, on account of the superior action of the sun and wind.

With respect to the form of the cross section of the road, it should not be too much curved, otherwise carriages will be driven in the centre where they can stand upright, instead of the sides, where, in very convex roads, it may even be unsafe to travel. It has been recommended that the cross section of a road should be formed of two straight lines inclined at the rate of 1 in 30, and united in the centre or crown of the road by a segment of a circle, having a radius of about 90 feet.

The external forces which diminish or destroy the momentum of carriages in passing over roads, are, 1, *collision;* 2, *friction;* 3, *gravity;* 4, the *air*. 1. The *collision* occasioned by hard protuberances and other inequalities in the surface of the road, tends greatly to impede motion; it produces resistance to the wheels, jolts and shocks, wastes the power of draught, and checks the forward motion of the carriage. 2. With respect to *friction,* if the road be soft and elastic, the wheels will sink in and the motion of the carriage be considerably impeded. Gravel roads, to which an appearance of smoothness is given by scraping them at great expense, and patching them with thin layers of very small gravel, are greatly inferior to a road properly constructed with stone materials. A smooth-looking gravel road is soft in comparison with it. It may be laid down as a general rule, that on every main road where numerous heavy waggons and stage coaches heavily laden are constantly travelling, the proper degree of strength which such a road ought to have, cannot be obtained except by forming a regular foundation with large stones, set as a rough pavement, with a coating of at least 6 inches of broken stone of the hardest kind laid upon it; and further, that in all cases where the subsoil is elastic, it is necessary, before the foundation is laid on, that the elasticity be destroyed, or at least diminished, by perfect drainage and other contrivances, and by laying a high embankment of earth upon the elastic soil, so as to compress it. Although a road, if made with a thick bed of well-broken hard stones laid upon the subsoil, may be, to all appearance, a hard and a good one, still the elasticity of the subsoil will have a considerable effect in adding to the tractive force necessary to draw carriages over it; for the subsoil will yield more or less under the incumbent weight. It is therefore only by proper drainage and pressure, and by making a foundation of large stones in the form of a regular pavement, that this elasticity can be effectively diminished. That this is the true principle of road-making, is now admitted by engineers and scientific men. Mr. Law well remarks on this subject, that "the outer surface of the road should be regarded merely as a covering to protect the actual working road beneath, which latter should be sufficiently firm and substantial to support the whole of the traffic to which it may be exposed. The real use of the road materials laid over it should be only to protect this actual road from being worn and injured by the horses' feet and the wheels, or from the action of the weather.

(1) Contour-lines are fine black lines, traversing the surface of the map in various directions, and where they approach the borders of the map figures are written against them: each of these lines indicates that the ground over which it passes is everywhere at a certain ascertained height, as expressed by the side figures, above some fixed point, termed the *datum*. These lines, by their greater or less distance apart, produce the effect of shading, and exhibit at one view the undulations of the surface of a country.

And this lower, or *sub-road*, as it may be called, being once properly constructed, would last for ever, merely the outer case or covering requiring to be renewed from time to time, so as always to preserve a sufficient depth for the protection of the sub-road." [1]

When a proper substratum of earth has been prepared for the bed or *formation-surface* of a road, a crust of materials must be so constructed upon it, that when consolidated it shall be hard enough to prevent the wheels of carriages from sinking or cutting into it. "For this purpose," says Parnell, "it will not be sufficient merely to lay upon the prepared bed of earth a coating of broken stones; for the carriages passing over them will force those next the earth into it, and at the same time press much of the earth upwards between the stones: this will take place to a great degree in wet weather, when the bed of earth will be converted into soft mud by water passing from the surface of the road through the broken stones into it. In this way a considerable quantity of earth will be mixed with the stone materials forming the crust of the road, and this mixture will make it extremely imperfect as to hardness, for it cannot in fact be perfectly hard unless it consists wholly of stones. It might be possible, in some measure, to cure this defect by laying on a succession of coatings of broken stones; but several of these will be necessary, and, after all, in long-continued wet weather, the mud will continue to be pressed upwards from the bottom to the surface of the stones. If even a coating of from 16 to 20 inches of stones be laid on, it will produce only a palliative of the evil. So that this plan of making a road will be not only very imperfect, but at the same time very expensive."

Mr. Telford's plan of making a regular bottoming of rough close-set pavement was adopted with signal success on the Holyhead Road, the Glasgow and Carlisle Road, &c. It secures the greatest degree of hardness, and is less expensive than when a thick coating of broken stones is used, for 6 inches of broken stones is sufficient when laid on a pavement, and the pavement may be made of any kind of common stone. If the bottom stones are laid with their broadest faces downwards and the interstices filled with stone chips well driven in, the earthy bed of the road cannot be pressed up so as to be mixed with the coating of broken stones. This coating, therefore, when consolidated, will form a solid uniform mass of stone, and be infinitely harder than one of broken stones when mixed with the earth of the substratum of the road. In this way the friction of the wheels on the surface of the road will be greatly reduced. Indeed it has been proved by experiment that the force of traction is in every case in proportion to the strength and hardness of a road. It was found that on a well made pavement the power required to draw a waggon was 33 lbs.; on a road made with 6 inches of broken stone of great hardness laid on a foundation of large stones set in the form of a pavement, the power required was 46 lbs.; on a road made with a thick coating of broken stone laid on earth, 65 lbs.; and on a road made with a thick coating of gravel laid on earth, the power required was 147 lbs.

3. With respect to *gravity*, it will be evident that, when a road is not horizontal, the force of gravity is a great impediment to the draught of the carriage, and considerably diminishes the effect which would otherwise be produced by a horse in drawing a load. 4. As regards the resistance of the *air*, this is very variable, but as its influence is the same for the same speed whether the road be good or bad, it need not occupy much attention. It is only on railways and at high degrees of speed that its power is felt. It appears from Smeaton's experiments that the force of the wind on a surface of 1 foot square was 1 lb. when the velocity of the wind was 15 miles an hour; 3 lbs. when the velocity was 25 miles; 6 lbs. at 35 miles, and 12 lbs. at 50 miles. Supposing the surface of that part of a carriage acted on by the direct influence of the wind to be 50 superficial feet, the resistance which it will meet with from a brisk gale of wind acting against it will be about 50 lbs. when the carriage is slowly moved; but if the carriage move directly against the wind with a velocity of 10 miles an hour, and the wind move with a velocity of 15 miles an hour, the resistance against the carriage will amount to 3 lbs. on the square foot, or 150 lbs. on the carriage, which is equal to the power which 2 horses should be required to exert when moving with a velocity of 10 miles an hour.

In marking out a line of road, much expense in cutting and embanking for making the *formation-surface* is avoided by a proper selection of high and low ground. The lowering of heights and the filling of hollows should be so adjusted as to secure gradual and continued ascending inclinations to the highest point. Skill is shown by the road engineer in so laying out the longitudinal inclinations of a road as to require the least quantity of cutting and embanking. For this purpose, he must measure and calculate the quantity of earth to be removed in cuttings so as to make it exactly suffice for raising the hollows to the required heights, a proper allowance being made for the subsidence of the soil. In making a deep cutting through a hill the slopes of the banks should not be less than 2 feet horizontal to 1 foot perpendicular, except in passing through stone: for although several kinds of earth will stand at steeper inclinations, a slope of 2 to 1 is necessary in order to admit the sun and the wind to the road. The green sod and fertile soil on the surface of the land cut through is to be preserved in order to be laid on the slopes as soon as they are formed. If sod is not to be had, the slopes must be covered with 3 or 4 inches of the surface mould, and hay seeds sown on it; by which process the slopes will soon be covered with grass, which will assist in preventing them from slipping. If stone is to be had, the slopes should be supported by a wall raised 2 or 3 feet high at the bottom: such walls prevent the earth from falling from the slopes into the side channels, and improve the appearance of the

(1) "Rudiments of the Art of Constructing and Repairing Common Roads." Published, 1850, in Weale's Rudimentary Series.

road. If an additional quantity of earth be wanted for an embankment, the slopes through the cuttings on the south side may be made of an inclination of 3 to 1: this will allow the sun and the wind to play more freely on the road. In rocky and rugged countries the inclination may be obtained by building retaining walls and filling between them with earth. In forming a road along the face of a precipice a wall must be built to support it. An inclination in the face of the precipice of ½ foot perpendicular to 1 foot horizontal will admit of a retaining wall being built. By building such a wall, say 30 feet high, and cutting 10 feet at that height into the rock and filling up the space within the wall, a road of sufficient breadth will be obtained. See Fig. 1831. In forming the bed of a road it should if possible be elevated by means of earth at least 2 feet above the natural surface of the adjoining ground, so as to prevent water from running under or soaking into it therefrom. This plan may not always be possible, for the surface must sometimes be cut into in order to get the proper longitudinal inclinations; but it is always desirable to get these inclinations by embanking rather than cutting, for there is always a better exposure of the surface on embankments, and a risk in all cuttings of the slopes falling down. One of the greatest defects of old roads is their being sunk below the adjacent fields.

Fig. 1831. RETAINING WALL.

Great care is required in forming embankments. The base must be formed at first of its full breadth, and the earth be laid on in regular layers or courses not exceeding 4 feet in thickness. In forming high embankments the earth should be laid on in *concave* courses: for if laid on in *convex* it is most likely to slip. In forming embankments along the sides of hills, *side-forming*, as it is called, the slope should be cut into level steps to receive the earth, which should be well compressed, and land-springs intercepted by proper drainage. For this purpose a drain should be cut on the upper side of the road, and open drains be made on the side of the hill above the road, to catch the surface water.

The slopes at which cuttings and embankments can be made with safety depend on the nature of the soil. In the London and plastic clay formations the slopes of embankments or cuttings, if more than 4 feet high, should not have a steeper slope than 3 feet horizontal for 1 foot perpendicular. In cuttings in chalk or chalk marl the slopes will stand at 1 to 1. In sandstone, if it be solid, hard, and uniform, the slopes will stand at ¼ to 1, or nearly perpendicular.

In making a road there must be provision for drainage, not only of the upper surface, but also of the formation surface. If the transverse section be gently convex, or of the form already indicated, the surface drainage will be assisted; but in addition to this, a ditch should be formed on each side of the road, of sufficient capacity to receive and carry off all the water that may fall on the road. Between the footpath and the road a channel or water course should be formed, and under the footpath, at distances of about 60 feet, drains of tiles or pipes should

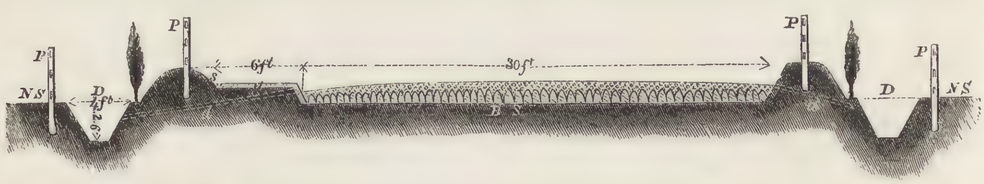


Fig. 1832. CROSS SECTION OF A NEW ROAD WITH A PAVED FOUNDATION. (*Telford.*)

B S, pavement, above which is a layer of broken stones. N S, natural surface.
P P, posts. *g*, gravel footpath. *s*, green sod. D D, main drains. *d d*, pipe drains.

be formed for conveying the water into the ditch. The small drains should not have too great a fall, or they will produce through them so rapid a current

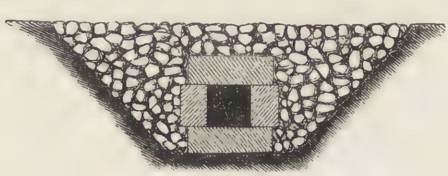


Fig. 1833.

that the ground about them will be washed away or undermined. If the surface be properly drained very little water will find its way to the substratum, except the latter be a strong clay, or of a wet peaty nature. In such case, a system of under-drainage must be resorted to, and trenches or drains be formed across the road at distances of 20 or 30 or more feet, according to circumstances. Each trench should contain a drain at least 4 inches square internally, made of old bricks, tiles, or flat stones, and the remainder of the trench should be filled up with coarse stones washed free from clay and dirt, as shown in Fig. 1833.

In places where stone is scarce, but gravel and lime abundant, concrete may be used for the solid foundation of a road with good effect. In laying it down it may be spread to the depth of 6 inches over the half breadth of the road; and upon this 6 inches

of good hard gravel or broken stone in 2 courses 3 inches at a time: the first course may be laid on a few hours after the concrete has been spread. No traffic must be allowed until the concrete has become hard and solid. The use of concrete allows a good solid road to be formed with round pebbly gravel and other materials not otherwise well adapted to road-making.[1] The gravel should be free from clay and dirt, and consist of stones and sand, the latter in sufficient quantity to fill up the interstices of the former. About 5 or 6 parts of such gravel are to be mixed with 1 part of ground unslacked lime, sufficient water being added to slack the lime: it is then to be thoroughly mixed up, immediately thrown into its place and trimmed to the proper form: the first layer of broken stones or screened gravel is then to be put on just when the concrete is about to set.

When the broken stones which cover a road are in angular masses they quickly wedge together into a smooth hard surface; but if the stones are round and pebbly, as most gravel stones are, they must be mixed with some binding material to fill up the interstices and prevent them from rolling about. Without this binding material such a road would not become solid; but its use leads to much inconvenience in wet weather, and especially in a thaw after a frost; the expansion of the water in freezing breaks up the road, and the subsequent thaw reduces everything to a loose spongy state.

The method of forming a road entirely of angular pieces of stone without any kind of binding material was adopted with great success by M^cAdam, whose name is perpetuated in the verb *to macadamize*. The stones used for the purpose must be hard and tough, such as the whinstones, basalts, granites, and beach pebbles, so that they may resist the action of the wheels. Hardness alone is not sufficient, for flint stones are hard, but brittle, and are soon crushed to powder, as are also, for a contrary reason, the softer sandstones: the harder and more compact limestones may be used, but all the limestones are retentive of water, and in frosty weather become disintegrated. The angular fragments must be of such a size as to pass freely by their largest dimensions through a ring $2\frac{1}{2}$ inches in diameter.

In situations where gravel is the only road material its bad properties may to a certain extent be removed by judicious treatment. When taken from the pit it should be passed over a screen that will allow all stones less than $\frac{3}{4}$ inch to pass through it, and the fine stuff or *hoggin* should be kept for forming footpaths, and of the remainder the large stones should be broken to the size of the gage-ring, and kept for the upper layer. The loam which accompanies the gravel serves as the binding material, and should not be separated; but the screened gravel should be spread over the whole road to the depth of 6 inches. The road may then be opened for traffic, and in this, as in other cases of new roads, men should be kept constantly employed upon it to keep every rut raked in as soon as it appears. *Guards* or *fenders* should also be so placed on the road as to make the carriages pass over every part of its surface in turn. Unless these precautions be observed the road will never become firm. When ruts are formed they mark out a kind of track which carriages follow, and thus the ruts are being continually widened and increased: in wet weather they become filled with water, which, not being able to escape, softens the materials, which are still further disintegrated by every vehicle. Thus the road becomes broken up and unsafe, and a much larger expenditure is required for its repair than for the permanent maintenance of a body of labourers upon it.

In chalk districts, this substance may be used for the foundation of the road, provided it can be placed at such a depth as to be beyond the influence of frost. If this cannot be done, the chalk may be used as a binding material with gravel on the surface, but it must be first reduced to powder and be well mixed with the gravel before laying it down.

In passing over soft and boggy ground, the foundation of roads should be laid with bushes or bundles of faggots at such a depth as to ensure their being always kept in a damp state; for if they become alternately wet and dry, they soon rot, and thus form a soft substratum to the road.

In improving old roads, it will often be found necessary to straighten their course by cutting off corners and bends; or to improve their levels by avoiding or lowering hills and embanking valleys; to increase their width and render it uniform throughout. The transverse section of the road must also be corrected, ruts filled up, and the side ditches cleansed and deepened: trees or hedges too near the road should be cut down, and mud banks removed. In improving a road it is not unusual for the surveyor to be satisfied with merely heaping on fresh materials; whereas, as Mr. M^cAdam remarks, "generally the roads of the kingdom contain a supply of material sufficient for their use for several years, if they were properly lifted and applied." In correcting the transverse form of the road, the parts which are too high must be cut down and the depressed parts raised, either by the proper arrangement of old materials or the addition of new. If these materials be not too rotten, too brittle, or too thin, the operation of *lifting* may be adopted. This consists in loosening and turning the surface of the road to the depth of about 4 inches, taking up large stones for the purpose of breaking them to the proper size, and removing other materials which are not in a fit state. If the materials are of such a nature that they would crumble on being lifted, then the surface of the road must be carefully cleaned from mud and dirt, and fresh materials be laid on in a coat not exceeding 2 or 3 inches in thickness. If the surface of the road is hard, but thin, all that may be neces-

(1) The employment of concrete of gravel and lime for roads was first proposed by Mr. Thomas Hughes, who has given instructions for its application in his work on "The Practice of Making and Repairing Roads," 1838.—See also Mr. C. Penfold's "Practical Treatise of the best Mode of Making and Repairing Roads."

sary will be to loosen it with a pick in order that the new material may quickly combine with the old.

As in wet weather the roads should be constantly scraped clean, so in dry weather they should be regularly watered. A long continuance of dry weather renders the road materials very brittle; they are ground to powder by the traffic, and the dust is wafted away by the winds. This may be prevented by regular watering; but the water-cart must not pour a deluge on the road, but should be so contrived as to produce the effect of a gentle shower of rain.

When fences are used they should be as low as possible, and placed as far from the sides of the road as possible, in order not to intercept the sun and the wind.

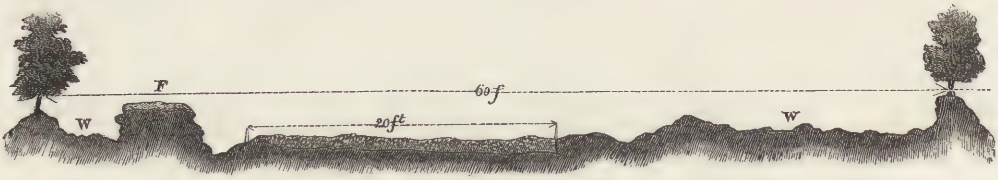


Fig. 1834. CROSS SECTION OF AN UNIMPROVED OLD ROAD.
W W, waste ground. F, footpath.

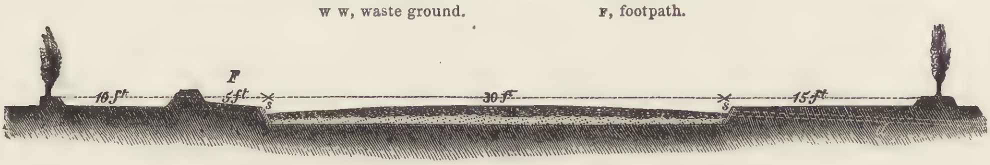


Fig. 1835. CROSS SECTION OF THE SAME ROAD WHEN IMPROVED.
F, footpath. *s s*, green sod. *d*, pipe drain.

The tools used in road-making are represented in the following figures. In working in clay, as in cutting deep drains, &c., a narrow *spade*, Fig. 1836, considerably curved in the blade, called a *grafting* tool, is used. The best kind of *shovel* for road work, Fig. 1837, is pointed in the blade, and has a curved handle, to allow the workman to bring the blade flat to the ground without stooping. When metal rails can be laid down, the *truck* or small *waggon*, Fig. 1838, is the best description of carriage for removing earth. It holds a cubic yard of earth. The body is of elm, the frame of oak, and the wheels and axles are of iron. Two

Fig. 1836.

Fig. 1837.

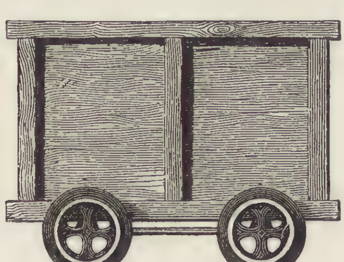


Fig. 1838.

kinds of *hammers*, Figs. 1839, 1840, are used in road works. The handles should be flexible, made of straight grained ash, particularly those for breaking pebbles. The small hammers should have a chisel face, and the larger ones a convex face, about $\frac{5}{8}$ inch in diameter. Those made of cast-steel wear better than wrought-iron, and seldom break at the eye. *Pronged shovels*, Fig. 1841, are useful for filling stones, when broken, into carts or barrows. A man can lift stones

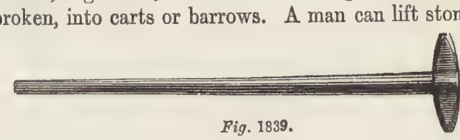


Fig. 1839.

more easily and quickly with one of these shovels than with a common one, and does not take up any earth with them. *Scrapers* are sometimes made of wood shod with iron, but those of plate iron are to be preferred: they should be 6 inches deep, and from 14 to 18 inches long in the blade, according to the materials of which the road is composed; the softer and more fluid

Fig. 1840.

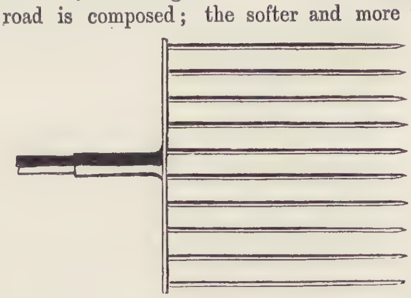


Fig. 1841.

the mud, the larger the scrapers should be. They should be turned a little round at the ends to prevent the mud from escaping. The best scrapers are made of old saw-plates, stiffened on the back by a rib of wrought-iron, or by rivetting the plate to a board of elm cut to the proper width and length, and about half an inch thick. The *patent road-scraper* consists of a series or row of scrapers placed in a frame, and mounted on wheels: it is worked crosswise on the

road, and deposits the dirt or dust on the side. It is easily worked by one man, and cleans above a mile of road per day, or about 5 times as much as can be done with the common scraper, and the work is better performed. The advantages of frequently scraping roads are, 1, the improvement of the surface, which cannot otherwise be kept hard and firm; 2, the facility afforded to fast travelling by removing a great obstruction to the progress of carriages; 3, the preservation of roads by removing the dirt, which absorbs and retains water on the surface; 4, assistance to the surveyor, by enabling him to take advantage of favourable periods of weather for cleaning his roads; 5, the saving of money, which may be applied to the strengthening and improving the roads. Mr. Whitworth of Manchester has contrived a machine for sweeping up the mud and carrying it away at once. It consists of a kind of endless broom passing round rollers attached to a mud-cart, and so connected by cog-wheels with the wheels of the cart, that when the cart is drawn forwards the broom revolves and

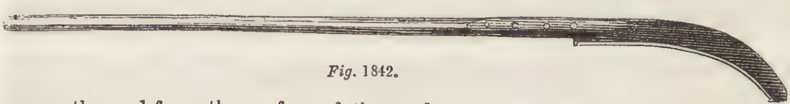


Fig. 1842.

sweeps the mud from the surface of the road up an inclined plane into the cart. Fig. 1842 is a *hedging knife*, or *plashing tool*, for trimming hedges, and if properly used, does the work as effectually as a pair of shears, and more quickly. It should be made sufficiently light to be used with one hand and be properly balanced on the handle, so that the man may wield it with proper effect. *Working levels*

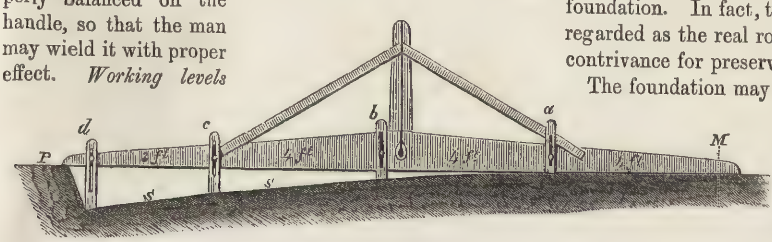


Fig. 1843.

are required in laying out new works, and in repairing old roads. M P, Fig. 1843, is a useful kind of level: on the horizontal bar are placed 4 gages, *a b c d*, made to move perpendicularly to the line M P in dovetailed grooves cut in the horizontal bar. When any one of these is adjusted to project a proper depth below the line, it may be fixed by a thumb-screw, which will retain the gage (shown separately in Fig. 1844) in the desired position. By means of this level the true transverse section of the road is formed. The plummet in the centre of the level shows when the straight-edge is horizontal. A line is drawn near the end of the bar at M, which marks the middle of the road; and at the distance of 4 feet from this point, the gage *a* is fixed in the groove by means of the thumb-screw, to the depth below the straight-edge required by the curvature of the road. The gages *b c d* are, in like manner, fixed, until their lower ends coincide with the surface which is to be given to a road 30 feet in width; and in order to ascertain whether the surface of any road is constructed to the required inclination and form, all that is necessary is to apply the level, which, having been made horizontal by means of the plummet, should rest upon the road at the lower extremity of each of the gages *a b c d*. *Levels* for laying out slopes are made of a bar of wood 3 inches deep, 1 inch thick, and 6 feet long: on the centre, near the middle of the rod, a triangular piece of wood of the same thickness is nailed; the sides of this triangular piece are so formed, that when the rod is placed upon a slope of 1 to 2 or 1 to 3, a small pocket level, placed on one side of the triangle, will be horizontal, and the bubble will remain in the centre. Fig. 1845 is a *ring-gage*, for ascertaining the size of broken stones.

*Fig.*1844.

Fig. 1845.

PAVED ROADS. In constructing roads through towns, where the traffic is considerable, it is desirable that the surface be paved. In such cases macadamized roads are dusty in dry weather, and muddy in wet: they produce less noise from carriages passing over them than paved roads; but if the latter are properly laid, the difference in respect of noise is inconsiderable.

In forming roads through streets it is even more important than in country roads to secure a good foundation. In fact, the foundation ought to be regarded as the real road, and the pavement as a contrivance for preserving it from destruction.

The foundation may be formed of concrete or of broken stone; and in cases where it is practicable the old road may itself form the foundation; for which purpose the stones are to be taken up and carefully laid down to the proper cross section, and upon this the stone pavement is to be formed. Where the foundation is formed of broken stone it should be as carefully laid out as for a macadamized road, and in that state it should be opened for traffic, and when properly consolidated the pavement should be laid on, the stones being bedded in some coarse kind of mortar.

When concrete is used for the foundation, the loose ground at the surface should first be removed to a depth depending on the nature of the ground, but generally to such a depth as to allow at least from 12 to 18 inches of concrete beneath the pavement. The stones should be well bedded upon the concrete in a kind of coarse mortar, which should also be filled in between the joints.

The best kind of stone for paving is granite: that from Guernsey and Aberdeen is the best, inasmuch as it does not assume a polished surface by wear which

is a defect of most hard stones. If limestone and freestone are used, the hardest varieties only should be selected. The best form for the stones is that of rectangular blocks, from 8 to 15 inches in depth, depending on the traffic, about 18 inches in length, and 3 or 4 inches wide. Experience has abundantly shown that narrow stones are preferable to wide ones. The stones must be sorted according to their depths and widths, for if of unequal depth they will form hollows on the surface, and if of unequal width they will not run across the road in parallel courses. The courses should break joint as in masonry or brick-work, and there should also be a good firm curb on each side of the road for the courses to abut against. In laying the stones, the courses should be begun on each side, and worked towards the centre; the joints between the stones should be thin, and the last stone should fit tightly, so as to form a key to the whole. The stones should then be well rammed down with a heavy punner, and any stone which falls below the general surface must be taken up and packed beneath. It is not usual to bed the stones in mortar in the manner recommended, but to pour over the surface a thin grouting of sand and lime after the pavement has been laid. This is a very poor and imperfect substitute for the plan with mortar, which, if properly carried out on a firm foundation, would produce a road almost indestructible.

Paved roads after they are opened for traffic should be constantly watched, and any stones which sink down should be taken up, and concrete put beneath them so as to raise them a little above the general level. The usual plan, in London at least, is to leave the road to its fate, and when it has become too bad to be used, it is taken up and relaid. The disturbance of the road for the repair of sewers or for laying down gas and water pipes is an evil which ought to be diminished as far as possible, and when the necessary work is done the road should be carefully restored to its former condition.

Where the inclination is considerable the pavement should be so laid that horses ascending with heavy loads may have a more perfect hold for their feet. For this purpose two methods have been adopted. That shown in Fig. 1846 is, to lay between the rows of paving stones a course of slate rather less than an inch in thickness, and about an inch less in depth than the stones. In this way a series of channels or

Fig. 1846.

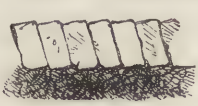


Fig. 1847.

grooves about an inch in width and depth is formed, which affords sufficient hold for the horses' feet. The other method, Fig. 1847, is, to lay the stones in a somewhat canted or sloped position, so as to form a series of ledges or steps which evidently assist a horse in ascending a hill with a load.

A few years ago wood pavements were introduced into London with a degree of zeal which, if it had only been tempered with judgment and discretion, might have ensured the permanent comfort of almost noiseless roads. Wooden pavements are declared to have failed, but no earnest attempt appears to have been made to ascertain the cause of failure with a view to its removal; the system was rapidly and extensively adopted, and hastily abandoned. Now the very same cause which leads to the expenditure of such large sums of money in the repair of roads led to the failure of wooden pavements, viz. the want of a solid foundation; and this want was sooner felt in the case of wood than in that of granite, on account of the less weight and inertia of the wood. In certain states of the weather the wooden surface was found to be slippery, but this might have been remedied; but there was no remedy for the numerous pits and cavities formed on the surface, except that which is required for all roads, viz. a firm and solid foundation.

The method of constructing asphaltum roads is described under ASPHALTUM.

RAILWAY, or RAILROAD, is a road in which rails of iron are laid down upon a smooth solid foundation for the purpose of facilitating the motion of wheel carriages. The power by which such carriages are moved does not affect the definition; they may be drawn by horses, or by locomotive steam-engines; they may descend inclines by their own gravity, or be drawn along levels and up inclines by means of stationary engines; the principles upon which railways are constructed will in all cases be nearly alike.

Nearly two centuries before the introduction of the locomotive steam-engine, the collieries of the north of England made use of wooden rails, tram or waggon ways, for the purpose of reducing the labour of drawing coals from the pit's mouth to the place of shipment. They consisted at first simply of pieces of wood imbedded in the ordinary road in such a way as to form tolerably smooth tracks for the wheels of the carts or waggons. It was found that by this contrivance the horses could perform a much larger quantity of work, or, still better, fewer horses were required for the same amount of work, thereby diminishing the number of servants, &c. These wooden railways do not appear to have been known out of the collieries,

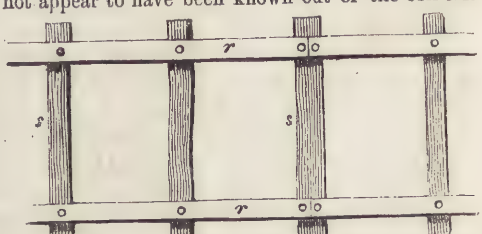


Fig. 1848.

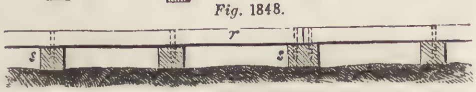


Fig. 1849.

but we learn something of their construction from the following description made about the year 1765:—The road was first levelled and reduced to as uniform an inclination as was generally practicable: roughly squared pieces of wood called sleepers *s s*, Figs. 1848,

W. H. Bartlett.

1849, about 6 feet long and 4 to 8 inches square, were then laid across it at a distance of about 2 or 3 feet from each other, and upon these other pieces, *r r*, carefully sawn, about 6 or 7 inches wide and 5 deep, were fastened by pegs so as to form two wheel tracks about 4 feet apart. The spaces between the sleepers and under the rails were lastly filled up with ashes, gravel, or other road materials.

In this arrangement the removal of a broken or worn-out rail injured the sleepers in consequence of the peg-holes becoming too large. But by spiking or pegging down a second set of rails *r′*, Fig. 1850,

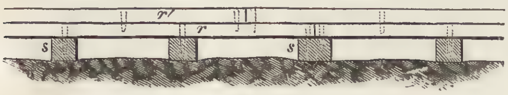


Fig. 1850.

upon the first *r*, the upper rails could be frequently renewed without disturbing the sleepers *s*. By thus raising the road a larger quantity of road material could be spread over the sleepers, whereby they were the better protected from wear. The waggons used on these wooden railways contained each about 2 or 3 tons of coal, and were mounted upon small wheels, furnished with a flange or projecting rim, which came in contact with the side of the rail and kept the waggon in its place. Such waggons were drawn by one horse. When the draught was harder than usual in consequence of a steep ascent or a sharp curve in the line, friction was diminished by nailing to the wooden rail thin plates of malleable iron. These lines were commonly constructed with a descent towards the river or seashore, and to prevent the descent from being too abrupt, it was usual to form an elevated *staith* at the river end of the line, and to shoot the coals from the waggons by an inclined plane into the holds of the ships. So also in cases where the incline would prove to be too steep if distributed equally over the line, the greater portion of the descent was made to incline gradually, and the rest of the fall was accomplished by one or more inclined planes of great steepness called *runs*, down which the waggons descended by their own gravity, the velocity being checked by a piece of wood called a *brake* or *convoy* pressed forcibly upon one or both of the wheels on one side of the waggon. This kind of railway continued in use for about 150 years without alteration, except a few attempts to introduce stone instead of wood: but it was found that what the *stoneways* gained in durability, they lost in smoothness. A great advance towards our present system was the introduction of cast-iron plates upon wooden rails, and it is a curious fact that this improvement was the result of accident rather than design. About the year 1767, when the price of iron was very low, it occurred to the proprietors of the Colebrook Dale iron works, as a means of keeping their furnaces at work, to cast bars in such a form as to admit of their being laid down upon a wooden railway in use at the works: this, it was thought, would save the expense of repairing the railway, but that if a sudden rise should take place in the price of iron, the rails could be taken up and sold as pigs. These bars or *scantlings* were 5 feet long, 4 inches broad, and 1¼ inch thick, and they were cast with 3 holes for the convenience of nailing to the wooden rails. The road was said to be successful, and it was pointed out as an advantage (which we should now consider to be a great misfortune) that vehicles could be turned off the track with great ease in consequence of the absence of a guiding flange. Attention was now called to this kind of road, and many attempts were made to combine the smoothness of a railway with the character of a common road. One of the best of these contrivances was that patented in 1803 by Mr. Woodhouse, who proposed to make rails of the form shown in section, Fig. 1851, to be imbedded in an ordinary pavement or road. The concave surface of the upper part of the rail was intended to keep carriages in the right direction, and yet allow of their being easily turned out of the road. Some of the iron gutters in the streets of London are made of this form, and the relief to the draught which they afford is known to every carman.

Fig. 1851.

Fig. 1852.

About the year 1776 the Colebrook Dale rail was improved by the addition of an upright flange, Fig. 1852, for the purpose of preventing carriages from running off the line. Rails of this form were first fixed upon cross sleepers of wood, as in Fig. 1853, for which purpose they were cast with holes for nails; and they were laid down with the flanges turned inwards, as shown in Fig. 1853, which is an end section of the two rails

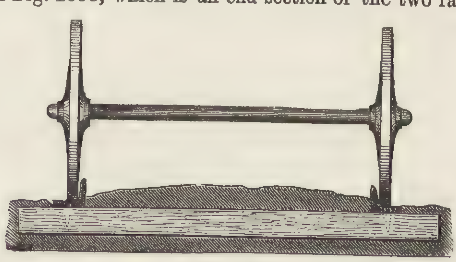


Fig. 1853.

fixed to a sleeper with a pair of wheels on them. About the year 1793 blocks of stone were used instead

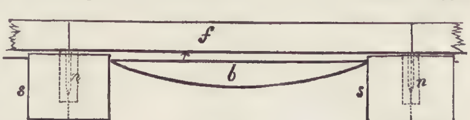


Fig. 1854.

of the wooden sleepers. Each block *s*, Fig. 1854, was about a foot square, and 8 or 9 inches deep; it was imbedded in the road under the junction or joint of every two rails, which were spiked down to wooden plugs *n* driven into holes in the stone. In this figure *r* is the rail, *b* the fish-belly, and *f* the flange. The increased durability of this plan over wooden sleepers was soon appreciated. This kind of railway, called the *plate* railway or *tram*road,[1] is still used in mining districts for the carriage of coal, iron-stone,

(1) From Mr. Outram, a gentleman extensively connected with the collieries. These roads were first called *outram* roads.

&c.: it is easily constructed, and the vehicles used upon it can also be run upon common roads. The form of the rail is, however, objectionable, and it allows stones and dirt to accumulate upon it, which not only impede the traffic, but tend to throw the carriage off the line. The defects of the plate-rails were remedied by the introduction of *edge*-rails, which were first extensively used in 1801, for the conveyance of slate from the quarries of Lord Penrhyn. They were of an oval section, Fig. 1855, the larger diameter being vertical. The length was $4\frac{1}{2}$ feet, and beneath each end was cast a dove-tailed block, which fitted into an iron sill imbedded in the road. The wheels had a grooved tire, fitting loosely on the rail; but it was found that the groove became so deepened by wear as to fit the rail tightly, and thus occasion much friction. An attempt to remedy this was by making the bearing surface of the rail and the corresponding part of the wheel flat, as shown in Fig. 1856. In spite of many defects, such was the saving of power on this line that 10 horses were found sufficient for work which formerly required 400 on a common road. A few years after the construction of this line, edge-rails were adopted by the coal owners of the north, and a better form of rail was contrived, viz. the *fish-bellied rail*, Fig. 1857, the lower edge being curved

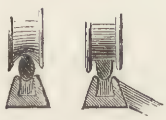


Fig. 1855. *Fig.* 1856.

Fig. 1857.

so as to give the rail greater depth in the centre than at the ends or points of support: *b* is the cross section of the rail at *c*, and *a* the cross section at the end. The rails were cast in lengths of 3 or 4 feet, and the ends so contrived as to form a half-lap joint, Fig. 1858 fitting into a cavity in a cast-iron chair *c*, spiked down to the stone or wooden sleeper, Figs. 1857, 1858, which show a side view and plan of the chair, &c. Fig. 1859 is a cross section of the rail and chair, with a portion of the tire of the wheel upon the rail. The flange used in the plate railway for keeping the carriage on the rail is in this example, Fig. 1859, transferred to the wheel, and this flange may be made smaller on the wheel than on the rail; and to prevent the flange from coming in contact with the rails more than is absolutely necessary, the wheel tire is made slightly conical. Fish-bellied rails have been superseded by *parallel* rails, or those which have an equal depth from end to end.

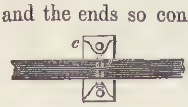


Fig. 1858.

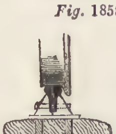


Fig. 1859.

A further improvement in rails was made by the introduction of malleable instead of cast-iron. Rails of cast-iron, especially those of the tram-plate form, were, from the brittleness of the metal, very liable to fracture, even when the carriages moved over them at a low rate of speed; and the attempts to remedy this evil by casting the rails of greater thickness, were not very successful. Rails of malleable iron, of the square or flat form, were laid down as early as 1808, this being the only form which the machinery of that time could produce economically. Attempts were made to form a cheap and durable rail by the combination of wrought and cast iron; but no plan was successful until the method was introduced in 1820 of rolling iron into any required shape. [See Iron, Fig. 1240.] The tough fibrous texture of wrought-iron makes it not liable to break from the blows and concussions of the carriages, while the form which is given to the rail prevents it from bending. It also allows of rails being made 15 feet long, whereby the number of joints is diminished; whereas with cast-iron rails the space between the points of support was not more than 3 or 4 feet, owing to the unavoidable shortness of the rail.

The waggons used on the cast-iron rails were made of small size in order to distribute the load over a considerable length of the line, and thus diminish the risk of fracture. Each waggon moved on 4 wheels, and being guided by the flanges on a straight road, the axles of the waggons were not attached, as in other vehicles, so as to allow them to turn by the wheels locking under the body; nor was it advisable to make the wheels revolve on the axles, but to fix them firmly thereto, and make the axle revolve in bearings attached to the body of the carriage. Iron wheels were used: where the traffic was slow, cast metal was employed; and for high speed, the most important parts were of malleable iron. Wrought-iron edge-rails were found to wear out cast-iron wheels very rapidly, and this led to the plan of case-hardening them. The carriages were further improved by being mounted on springs.

With respect to the power employed for moving the carriages on railroads, the locomotive steam-engine was slow in making its appearance. Animal power was used in transporting mineral produce to the place of shipment; and as the loaded waggons generally had to descend to the river or to the sea-shore, gravity was also made use of, and in some cases superseded animal power. Where the incline was very steep, animal power could not be used. In such cases a self-acting inclined plane was employed, on which a train of loaded carriages was allowed to descend by the force of gravity: to this train was attached a rope which, after passing round a wheel at the top of the incline, proceeded down the slope, and was fastened to a train of empty waggons, so that the force of the descent of the loaded train was sufficient to cause the empty train to ascend to the top of the incline. This excellent arrangement still continues in use. In other cases, where the ascent was too great for horses, the carriages have been drawn up by the power of stationary steam-engines by means of ropes guided by pulleys in the centre of the track. With respect to the locomotive or moveable steam-engine, a suggestion for such an engine occurs in one of the patents of Watt as early as 1784, but such an

engine does not appear to have been constructed until 1802, when Messrs. Trevithick and Vivian took out a patent for a high-pressure engine, which in 1805 was worked on a tramway at Merthyr Tydvil. This engine, although simple in its structure, possessed all the essential arrangements of modern engines. Trevithick found, that the adhesion between the wheels of the engine and the rails was sufficient for progressive motion on a level or nearly level line, yet he feared that, on too steep an incline, or with too heavy a load, the wheels would slip round on the rails without advancing, and he proposed to remedy this by making the driving-wheels uneven by means of projecting bolt-heads, cross grooves, or fittings to the rails. This idea prevailed for many years, and engineers, instead of trying the experiment, exerted their inventive powers to remedy the imaginary evil. In 1811, Mr. Blenkinsop patented a locomotive engine in which the driving-wheel was furnished with cogs, which entered a rack laid down by the side of the ordinary rails. This plan was put in action on a colliery line near Leeds, but the friction was found to be so great that the plan was abandoned. In 1812, Messrs. Chapman constructed engines on 8 wheels, all of which were driven by the power in order to increase the adhesion. About this time Mr. Brunton constructed a locomotive machine, which was made to advance by the alternate motion of 2 levers thrust out from the back of the engine. Similar propellers were used by Gordon and Gurney on common roads. In 1814 and 1815 engines with plain wheels were again tried, and being found efficient, were used upon some of the northern railways. In 1816 and 1817 patents were taken out by Messrs. George Stevenson, Dodd, and Losh, for locomotives, which were used upon colliery railways near Newcastle-upon-Tyne. It was not, however, until the Liverpool and Manchester railway approached completion, that any serious attempts were made to apply the locomotive to the purpose of passenger traffic. The Stockton and Darlington railway, opened in 1825, gave a very favourable idea of the great value of railways for the conveyance of passengers and goods even when animal power was used, as it was on that line. But the expense of animal power at a speed of 8 or 10 miles an hour was found to be great, and as the directors of the Liverpool and Manchester line aimed at a high rate of speed, it was proposed to erect fixed engines, at intervals of a mile or two along the line, and to draw the trains, from station to station, by means of ropes. Fortunately for the interests of railways, it was determined to employ locomotives, and to offer a premium of 500*l.* for the best engine: this engine was not to produce smoke, it was to draw 3 times its own weight at the rate of 10 miles an hour; it was to be supported on springs; it was not to exceed 6 tons in weight, or 4½ tons if it ran on 4 wheels only, and it was not to cost more than 550*l.* Trial of the engines was made in October 1829, when 4 steam locomotives were produced, one of which was withdrawn at the commencement of the trial. Of the other 3, the *Novelty*, by Messrs. Braithwaite and Ericson, promised good results, but an accident with the boiler crippled it during the trial. The *Sans Pareil*, by Mr. Hackworth, attained a velocity of 15 miles per hour with a gross load of 19 tons; but an accident happened to this engine also, which put an end to the experiment. The third engine, the *Rocket*, by Messrs. Robert Stephenson and Booth, surpassed the stipulated conditions and won the prize. Its average speed was 14 miles an hour with a gross load of 17 tons, but under certain circumstances it attained double that velocity.

The experiment thus tried produced the most satisfactory impression upon the public mind. The possibility of constructing railways in certain situations, Chat-Moss for example, had even been denied by engineers of repute, and the attempt to form locomotives for moving laden carriages at a high rate of speed (as 10 miles an hour was then called) had excited the smiles of scientific men. But now that the thing had been done, that a speed far superior to that of horses had been attained, men scarcely ventured to limit their anticipations for the future. The traveller, whether for business or for pleasure, had vivid impressions of the discomfort of a slow and toilsome journey by coach from one part of the kingdom to another, and he now ventured to hope that soon he might be able to travel at the rate of at least 20 miles an hour! We need not, however, now refer to the prospect of railways in 1830, since the most sanguine expectations of that time have been more than realized.[1] Railways have spread their civilizing net-work over the face of the earth, and have been a powerful means of bringing the human family into closer union; the system is still extending, and let us pray that its effect may be to hasten the coming of that happy time when "the knowledge of God shall cover the earth as the waters cover the sea."

Curves and Gradients.—The laying out of a line of railway is a more important operation than that of a common road. Not only is the railway more costly than

(1) At the commencement of 1851, the length of railways in actual operation in the United Kingdom was as follows:—

England and Wales	5132 miles.
Scotland	951 ,,
Ireland	538 ,,
TOTAL	6621 ,,

The lengths of line opened in the following successive years were:—

1843 (and earlier)	2036 miles.
1844	204 ,,
1845	296 ,,
1846	606 ,,
1847	803 ,,
1848	1182 ,,
1849	869 ,,
1850	625 ,,

The following is the amount of the traffic:—

Year.	Total.	Weekly average per mile.
1842	£4,341,781	£60
1843	4.842,625	59
1844	5,610,982	63
1845	6,669,224	66
1846	7,689,874	62
1847	8,975,671	55
1848	10,059,006	49
1849	11,013,817	44
1850	12,775,235	43

the road, but it must approach more closely to the definition of a perfect road. The theory of a perfect railway is, that it shall follow a right line, and be uniformly level from end to end. There are but few parts of the world where such perfection is attainable; the presence of hills, rivers, canals, towns, and dépôts, and the difference of level at the intended termini, preventing the formation of such a line.

When the termini and general course of the line have been decided on, a careful survey is made of the country to be passed over; its elevations and depressions are carefully noted, together with the roads, water-ways, towns, &c., that have to be avoided, crossed, or visited; and the geological structure of the country must be ascertained. The facts thus collected will determine what lateral and vertical deviations from a perfectly straight horizontal line will be required, or, in other words, what will be the *curves* and the *gradients*. The width of the surface is determined by the intended gage of the line and the slopes of its cuttings and embankments. In order to the proper adjustment of the gradients, a section or profile of the line of country is prepared, in which the elevations and depressions are drawn to a much larger scale than the horizontal distances, so as to make them more appreciable to the eye by making them disproportionably steep. It is required under the standing orders of Parliament respecting railway bills, that plans and sections of the proposed line, on a scale of 4 inches to a mile, shall be deposited with the Clerks of the Peace for the several counties through which it is proposed to carry the railway, on or before the 1st March, and in the Private Bill Office on or before the 1st April, in the year preceding that in which an application is made to Parliament for an Act. The process of obtaining a railway Act does not belong to our subject, but we may state that the Act, which forms the shareholders into a corporate body, with powers to construct the line, generally allows a deviation from the line laid down in the plan to the extent of 100 yards in the country, but only 10 yards in towns. Power is also given for altering to a limited extent the levels and gradients defined on the parliamentary section. In this country the laying out of a railway, as well as its construction, like most other great engineering works, is left to private enterprise. It has been contended that a system of railroads should be laid out by the government of a country, in order to ensure some uniformity of plan, which shall promote the general convenience, and yet not cut up the land unnecessarily, or conduct lines through dangerous localities. Most of the continental lines have been laid out under government control; although many of them have been constructed and worked by private companies.

The lateral deviations from the theoretical straight line of a railway can only be made in *curves*, angles not being compatible with speed, nor with the permanently parallel axes of the 4 and 6-wheeled carriages impelled thereon. As the perfect condition is a right line, so the minimum amount of deviation therefrom will produce most satisfactory results in the working; and this minimum deviation can only be produced by making the curves of the largest possible radius, arranging the line so as to have the smaller curves near the stations or stopping-places. This arrangement is necessary not only for speed, but also for safety. In moving over a curve at a high rate of speed, the effect of centrifugal force tends to throw the train off the line. There are also other objections to curves, which engineers have endeavoured in various ways to remedy. For example, in moving on curves the wheels on the inner rail will attempt to describe a smaller curve than the wheels on the outer rail, and will thus be made to rub backwards and forwards on the rail while the outer wheels are getting over the excess of space; this produces torsion of the axles and straining of the frame and the parts connecting it with the axles. Attempts have been made to remedy this source of evil by giving a conical form to the tires of the wheel, and by slightly raising the outer rail. The tires are so arranged that the bases of the cones are towards each other, and it is assumed that when the centrifugal force drives the flange of the outer wheel towards the edge of the rail and withdraws the flange of the inner wheel from its rail, the diameters of the wheels are rendered practically unequal in the exact proportion required to get rid of the dragging which takes place when cylindrical wheels of equal diameter, locked together on the same axle, are made to describe curves. The tendency of the carriage to proceed in a straight line instead of a curve is usually counteracted by the rubbing of the flange of the wheel against the rail: the object of making a slight ascent to the middle of the curve is to diminish this forcible friction. The extent to which these two corrections are applied may be illustrated by the following example given by De Pambour:—With an average velocity of 20 miles an hour, a radius of curvature of 500 feet, the wheels 3 feet in diameter, the gage of the railway 4·7 feet, and the play of the wheels between the rails 2 inches, the least inclination that should be given to the tires of the wheels is $\frac{1}{12}$th; that is, the tire should belong to a cone the radius of whose base is to its axis as 1 : 12. It is usual to give an inclination of $\frac{1}{7}$th. With the same data the outer rail of the curve should have a surplus elevation of 2·83 inches.

At or near the termini and junctions, which are always approached and departed from at a very diminished speed, curves of small radius may be used. On the Chester and Crewe line, the Crewe terminus is quitted in a curve of 18 chains radius; and the Grand Junction joins the Liverpool and Manchester line in two curves of 10 chains radius each. Such curves as these cannot, however, be commended even at stations, for it is necessary in order to allow mail and other trains to pass first and second-class stations at full speed, that the largest possible curves be adopted throughout the line.

The deviations from the horizontal level form the *inclinations* or *gradients* of the railway. These must

be considered with reference to economy in the construction of the line,—as to how much earth-work, tunnelling, bridge-work, &c., may be saved consistent with the required velocity, the expenses of engine-power, the wear and tear of engines, carriages, and brakes. Where the gradients are steep the cuttings are required to be of less depth, and the embankments of less height; a smaller quantity of land is required, and the ratio of saving, both in land and labour, increases rapidly upon the proportion of height or depth avoided: there is also a large saving in the size and cost of bridges and cuttings, and bridges or viaducts under embankments, &c. But, as already stated, it must be considered how far these sources of economy in the first cost are counterbalanced by increased expense in locomotive power, repair, and economy of time. The opinions of engineers are much divided on the subject of gradients. It has been stated that an elevation of 20 feet requires an exertion of force equal to that on a mile of level railway; so that the same power which would move a given load over one mile of railway rising 1 in 264, or 20 feet in the whole, would move the same load over 2 miles of level road. Another view of the case is, that an alternation of steep and easy gradients is as advantageous as a gradient of medium steepness, the rise being the same in both cases. If this be so, the important fact is established, that it is not necessary to spend vast sums of money in reducing hills and filling up valleys, at least to such an extent as has been done on many of the great lines, for the purpose of making the gradients as easy as possible.[1] The advocates of the system of alternating steep with easy gradients, or with levels, maintain that a compensating effect is produced in descending and ascending gradients, and that a variation of speed in the train is the whole amount of inconvenience that will ensue.

In confirmation of this view of the case we may refer to some experiments made by Dr. Lardner in July, 1839, when the Hecla engine with 12 carriages, making altogether a gross weight of 80 tons, was run from Liverpool to Birmingham and back in the same day; by which means the same train, under as nearly as possible the same circumstances, had to ascend and descend every plane on the line for a length of about 95 miles. The time of passing each quarter-mile was carefully observed, so as to obtain the speed on every part of the road. The following table gives the results of observations on gradients varying from a level surface to 1 in 177, or nearly 30 feet per mile:—

Gradients, 1 *in*	*Speed in ascending. Miles* per hour.	*Speed in descending. Miles* per hour.	*Mean speed. Miles* per hour.
177	22·25	41·32	31·78
265	24·87	39·13	32·00
330	25·26	37·07	31·16
400	26·87	36·75	31·81
532	27·35	34·30	30·82
590	27·37	33·16	30·21
650	29·03	32·58	30·80
Level	——	——	30·93

(1) It has been calculated that the railways existing in 1842 had cost on an average about £34,700 per mile; in 1846 this average was estimated at £31,800, and at the end of 1850 £35,200.

Thus, taking the velocity on the level surface at 31 miles per hour, it will be seen that this rate was lowered to a little over 22 miles an hour in ascending an incline of 1 in 177; but the increased rapidity of the descent more than compensated for the loss, the mean velocity being 31·78. The mean speeds on the different gradients vary slightly, but the result of this interesting experiment seems to show that a line of railway with gradients of from 20 to 30 feet per mile, may be worked in both directions by the same expenditure of power as a dead level. We do not give this as an established conclusion, but refer to it as an interesting subject for inquiry. Although some of the most eminent engineers have expressed themselves strongly in favour of easy gradients, a plan has been getting into use which accommodates both steep and easy gradients, and vastly diminishes the cost of construction. This plan is, to accumulate the ascents as much as possible into short steep planes, which are to be worked by means of assistant engines, either motive or stationary. Although by this plan there is no saving of power, there is a saving of time, and it is not necessary to reduce the amount of load below what would be otherwise considered most advantageous for the general traffic. Whereas with steep gradients, not accumulated, but distributed over the line, the engines must work with small loads. For example, in ascending a plane of 1 in 140 with a load of 100 tons, the force of traction requires to be doubled, or be made equal to 200 tons on a level. Or, in order that the engine may ascend the plane without assisting power, the load must be reduced to 60 tons; the expense of haulage up the incline is increased 36 per cent.: so that not only is the equivalent horizontal plane about one-half longer than the real length of the actual plane, but the expense of working the whole distance is increased 36 per cent.

In answer to this case, which was given in the Report of the Irish Railway Commissioners, Mr. Vignoles states as the result of his long experience, that scarcely once in 20 times does a locomotive engine go out with more than half its load, and in general, engines are only worked up to $\frac{2}{3}$ths of their power. He therefore states his conviction that it is cheaper to put on an additional engine on extraordinary occasions, and hence that railways should be constructed through the more remote parts of the country so as to be made in the cheapest manner, that is, not to attempt to produce very easy gradients.

Whatever be the ratio of inclination for the gradients, it is necessary for the sake of economy, safety, and convenience in working the line, that the gradients contiguous to stations should always rise towards them in either direction, so that every station may occupy the summit of two adjoining gradients. By this arrangement an impetus is given to the engine in starting, and a salutary check is afforded to the speed of the engine and train on arriving at a station; thus rendering unnecessary the action of a powerful brake, which is as destructive to the wheels of waggons as it is to the rails. The value of the incline in starting the engine is very great, since every

engine in starting has to exert an additional effort: when motion is once created the moving power need only be constantly equal to the resistance; but in putting the mass into motion, the power must exceed the resistance; for in one case it is only necessary to maintain the speed; in the other it must be created and maintained. The difficulty in starting is always great for considerable loads, and hence the value of a slight declivity. It is advisable to separate long inclines of considerable steepness into two or more lengths by the introduction of short planes, either level, or inclined in opposite directions. These *breaks* or *benches*, as they are called, act as resting-places to the loaded engines, giving the driver an opportunity of easing the steam-pressure in ascending, and serving to moderate the speed in descending.

The speed of a railway-train creates as it were an opposing power in the resistance of the air; but the retarding effect due to its displacement has not been correctly ascertained. The "Second Report on Railway Constants," presented to the British Association at its eleventh meeting, contains some interesting experiments on this subject. It was found that with a train of 8 carriages moving with a velocity of 30 miles per hour, the resistance to the speed was about 15 lbs. per ton, or almost double the value of the resistance from friction only. As to the effect of external configuration on the resistance of the air, the Committee concluded from their experiments "that the form of the front has no observable effect, and that whether the engine and tender be in front, or two carriages of equal weight, the resistance will be the same. The intermediate spaces between the carriages were closed in by stretching strong canvass from carriage to carriage, thus converting the whole train into one unbroken mass. The results were in favour of the train without canvass, but the differences are extremely slight: it is certain that no additional resistance is occasioned by leaving open spaces between the carriages, confining the intervals to the dimensions allowed in practice."

Gage of the Line. The determination of the gage, or width between the rails, is a point of great importance, for on this width depends to a certain extent the kind of locomotive which can be used, the size of passenger-carriages, the bulk of merchandise and goods that can be conveyed, the steadiness of motion, and the safety and facility in passing round curves at high rates of speed. The gage has also an influence on the quantity of land required for the line, on the width of bridges, viaducts and embankments, cuttings, tunnels and stations.

There are 3 widths of gage in England, viz. 4 feet 8½ inches, 5 feet, and 7 feet. There are 2 widths in use in Scotland, viz. 4 feet 6 inches, and 5 feet 6 inches. There is yet another gage in Ireland, viz. 6 feet 2 inches.

Previous to the formation of the Great Western Railway the gage in use in England was 4 feet 8½ inches. Brunel made the considerable increase of 2 feet 3½ inches, on the ground that the 7-feet gage would allow of an increased speed, in consequence of the employment of larger and more powerful engines; of diminished friction owing to the larger diameter of the wheels; of increased stability and steadiness from the method of placing the body of the carriage within the wheels, whereby the centre of gravity of the carriage would be kept low; of increased accommodation for the conveyance of bulky goods, &c. In opposition to these advantages have been opposed the increased cost of the line; the larger and heavier carriages and their increased cost; the additional friction in passing through curves, and the greater liability to the fracture of axles; and, lastly, the impossibility of forming a junction with other lines.

Slopes, Cuttings, and Embankments.—The inclination of the earth-works, whether for excavations or embankments, must be determined mainly by their height, and the nature of the material excavated, or of which the embankment is composed. In stratified rocks, the tendency of one stratum to slip upon another, requires that the slopes shall be much less steep than would be safe in unstratified materials. The slipping of one stratum upon another may be caused by the passage of water, or by the action of frost between the strata, and can only be prevented by draining the faces of the cutting and extending the drainage backwards for some distance, so as to collect all the water that may find its way into the neighbouring soil, and carry it off before it has time to get to the face of the work. A complete system of superficial drainage must also be provided for the water that collects on the surface of the cutting. Probably the worst kind of stratification which the engineer has to encounter is an alternation of sand and clay. When these materials are mixed, the work is safer. Stony soils, or a mixture of sand and gravel, become compact and hard. In passing through rocks the excavation may be formed with steep sides; but if the rock be liable to disintegrate by moisture or by frost, a greater flatness must be allowed. Chalk may be cut with nearly vertical faces, its own cohesion being sufficient to support it. In general it will be found that an angle a few degrees less than that of repose, will answer both the conditions of economy and stability, and a little extra attention to drainage will be cheaper than giving additional flatness to the slopes. The banks must be preserved with care by covering them with turf or with the surface soil, and they must be sowed with grass seeds. Spade-cuts or channels passing obliquely from the summit of the slope to the drain at the base, so as to form a repeated outline of the letter V on the face of the bank, the V's in some cases intersecting, will form cheap and efficient superficial drains.

In cases where shale, or other soft stratum lying under stone, such as limestone, is found to rise above the level of the bottom of the cutting, a portion of such shale or soft stratum is to be excavated from under the limestone on each side of the cutting, and be replaced by walls, buttresses, arches, and inverts. The excavation at Blisworth, on the North Western Railway, furnishes an instructive example of this kind of work. The principal excavation is about 126

chains in length, and 53 feet in its greatest depth. The strata intersected are the upper soil S *s*, Fig. 1860, of a light sandy kind, with clay from 2 to 10 feet thick, and lying mainly in blue, yellow, and brown marl, and red clay, of an average thickness of 20 feet. Under these is the limestone rock R R, of various degrees of hardness, and in beds of 1 to 4 feet in thickness, but without any mixture of shale, and having springs of water in the lower beds. At the east end of the section the limestone rock crops out, and the superior stratum of marl disappears. Beneath the limestone is the blue shale: it appears to be dished on the upper surface, being about 6 feet thick at the east end, extending about 20 chains, then ranging beneath the railway level, rising again at the end of 75 chains, and acquiring a thickness of nearly uniform increase of 30 feet at the western extremity of the section, where it outcrops beneath the limestone.

At the west end the excavation is formed to a slope of 2 feet base to 1 foot height throughout its whole

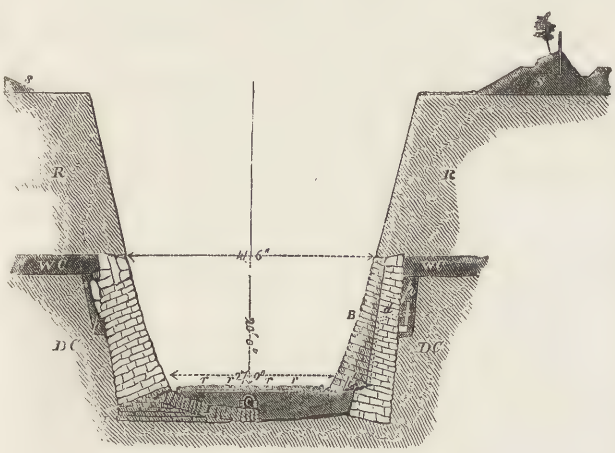


Fig. 1860.

depth for a distance of 22 chains, the inferior stratum of shale being faced with rough stones. Through

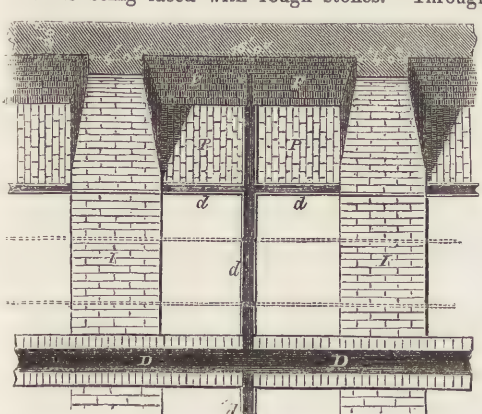


Fig. 1861.

the next distance of 38 feet the opening is narrowed by a winding *batter*[1] on each side, to a section corresponding to that shown in Fig. 1860 The lower part, extending upward to a height ranging with the undersetting of masonry beneath the rock, which is continued throughout the excavation, is formed to a curved batter of 106 feet radius. The average vertical height of this undersetting above the level of rails is 20 feet. The rock above is sloped at $\frac{1}{4}$ to 1, a benching of 9 feet wide being left on its upper surface, and the superior soil trimmed to a slope of 2 to 1. The method of draining is also shown in the figures, together with the inverts I and buttresses B for supporting the undersetting. Fig. 1860 is a cross section, one half being taken through the wall, the other through one of the buttresses. Fig. 1861 is a sectional plan of half of the excavation, showing the recess wall, 2 feet 6 inches thick at top, battered in front to a slope of 2 inches to 1 foot. The centre drain D, 1 foot 9 inches wide; and the cross drains *d d*, are shown in section. P P shows the pitching and I I the invert arches. Midway, between each 2 contiguous buttresses, a vertical drain, or gullet, *d*, is formed on the face of the wall, receiving the drainage water by oblique drains, shown in dotted lines, from the puddling *p* at the back of the wall.

The quantity of material removed from some cuttings is enormous. Thus, to cite a few examples:—the Oakenshaw cutting on the North Midland railway is in rock-shale and bind: the greatest depth is 50 feet, and its contents 600,000 cubic yards, most of which was led to form the Oakenshaw embankment. The Normanton cutting has a maximum depth of 55 feet: it contained 500,000 cubic yards, chiefly rock, and blue bind: most of this was led to form the Altofts embankment, and 70,000 cubic yards were thrown out "to spoil." The progress of the works was so rapid in 1839, that 450,000 cubic yards of excavation were effected per month. The number of men employed was 8,600, and there were 18 fixed engines working chiefly at tunnels. Much trouble and expense are occasioned by the slipping of the slopes. In a cutting which was to be formed in the side of a hill in the north of England, it was calculated that about 50,000 cubic yards of earth would have to be removed. It happened, however, that the soft earth was upheld by a seam of shale, which was no sooner cut through than a mass of earth slipped down into the line of the railway, to such an extent as to require the removal of about 500,000 cubic yards.

In excavating through hills of considerable height, it is important to get a fair face to the work, or one at right angles to the direction of the cutting, and from this face to start a system of *gulleting* or *notching*. In this way labour is economised. As the work proceeds into the hill, and the width is increased in order to provide for the slopes, it is desirable to run a gullet along the centre of the cutting, in order to bring a larger number of waggons into use at one

(1) Probably from the French verb *bâtir*, to build.

time. In this gullet temporary rails are laid down, and the train of waggons is sent forward to receive the produce of the barrowing on either side. As the height of the hill increases, a second layer is commenced, and a side track is laid, inclining down on each side of the lower level. On these lines the full waggons descend on one side, and the empty ones are drawn up by horses on the other. Horses are also used for moving the full waggons to the head of the incline, down which they descend by their own weight. One of the great inconveniences of excavating is the accumulation of water in the lower parts of the cutting: this is prevented by keeping the bed of the cutting inclined upwards so as to conduct the water away. When the *lead* is in both directions from the centre of the intended excavation, and it is required to send the materials got out to each end of the hill, the excavation is begun at both ends and terminates in the middle: in such case there is a rise from each end to the centre for the purposes of drainage. In many cases the plough is used preparatory to excavation: it is very effectual in loosening the surface. In America a *scoop* has been found of advantage.

In so extensive a work as a railway over an undulating surface, it is of great importance that the amount of excavation and embankment should be balanced as nearly as possible, to prevent the necessity of depositing the earth from cuttings in *spoil-banks*, or of having to purchase land for furnishing material for embankments. If a cutting were found to yield a surplus of material, a short tunnel would be preferable to a cutting; but if material for embanking be wanted, then the cutting would be preferable to the tunnel. It is generally contrived, for the sake of economy, that a cutting and an embankment shall be carried on simultaneously; but the cost of the embankment will be considerably influenced by the length of the *lead*, or the distance to be traversed by the earth-waggons between the points of filling and emptying. The usual and quickest mode of forming an embankment is by running it out to the full depth required at once. The front end of the embankment where the formation is proceeding, and over which the material is *tipped*, is called the *battery-head*. Temporary lines are laid down with edge-rails and wooden sleepers, in a double line, with crossings near the battery-head for the waggons to cross over as soon as they have tipped over their contents, when they return to be filled by one line, while the full waggons are proceeding along the other.

The method of forming embankments for common roads has already been noticed. The subsidence of newly-made embankments, in some cases leads to considerable expense and even danger. There are various methods of embanking, that method being the best which combines stability with economy. With this view many engineers prefer to run forward the two sides of the embankment to the full width, leaving a central valley to be filled in at some little distance in the rear. The effect of this arrangement is, that the two sides act as separate embankments, and resist the thrust of the central part afterwards put in; and any alteration in form and position is less likely than if the banks were carried forward with one battery-head across the whole width of the work.

The kind of waggon employed in embanking depends to some extent upon the material. Those called *end-waggons*, Fig. 1862, discharge their load from the back or end; *side-waggons* are emptied at the side. The waggons move on a hinge, and by the motion of a lever are tilted or tipped over as soon as

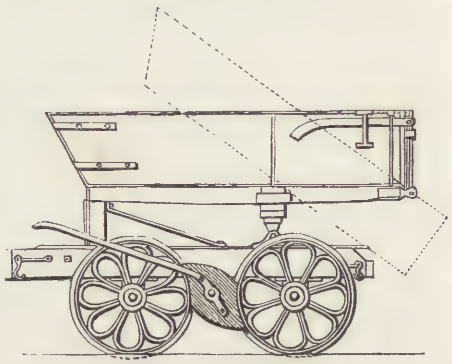


Fig. 1862.

the wheels strike against a fixed stop or bar at the battery-head. Fig. 1863 shows a form of waggon which is more readily emptied than when the body

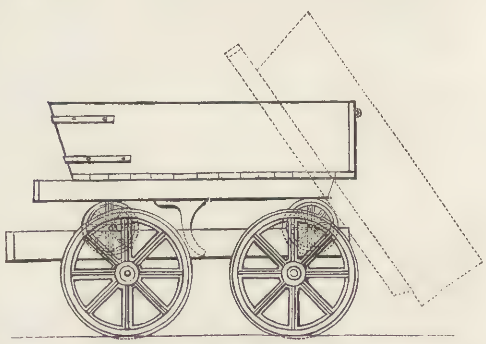


Fig. 1863.

turns on a hinge. The body is supported on 2 rollers, and when the waggon suddenly stops at the tip, the momentum of the load carries the body forward until its centre of gravity gets beyond the support, and the body is instantly tilted. The body is prevented from overrunning by a pair of curved metal stops, which are checked against the front rollers. All the waggons are provided with simple brakes, consisting of a block of hard wood, shaped so as to fit a portion of the periphery of the 2 wheels, and capable of being turned on a centre by means of a long handle of iron which is carried to the front or hind part of the waggon, so as to be acted on by the hand or foot of the brakesman. The handle moves within an iron slot, and may be secured in any position by a pin passed through it. The earth-waggon is nearly square in form, having a slight taper or increase of width towards that end of the waggon which is turned downwards in the act of tipping. Each waggon contains about 2½ cubic yards: the wheels are 3 feet in diameter; the wood-work is

of English elm. Under the framing a sole should project beyond the body to leave room for the driver to escape in case the sole ends or buffers should be forced violently together. Waggons are also constructed of iron.

One of the most celebrated embankments is that over Chatmoss, on the Liverpool and Manchester line, formed in the infancy of railroads, and in opposition to the opinions of eminent engineers as to its practicability: some declaring before a parliamentary committee that it would be utterly impossible to carry a line over this bog without first cutting down 33 or 34 feet to the solid bottom; others declaring that a cost of 200,000*l*. would not suffice for the work: and yet, although the moss contained nearly double its bulk of water, a safe embankment was formed over its surface at a cost below the average of other parts of the line. The tribute of respect paid to the engineer of this great work by a celebrated French writer,[1] will be a sufficient excuse for quoting the passage:—

"The depth of the moss varied from 10 to 34 feet, and its general character was such that cattle could not walk on it: the subsoil was principally composed of clay and sand, and the railway had to be carried over it upon a level, and required cutting and embankment for upwards of 4 miles. Where the mode of doing this required an embankment, the expense of which, in the ordinary method, would have been enormous, as it must have been bottomed upon the subsoil of the moss, Mr. Stephenson contrived to use the moss itself in the following manner:—Drains about 5 yards apart were cut, and when the moss between them was perfectly dry, it was used to form the embankment, and so well did it succeed, that only about 4 times the quantity was required that would have been necessary on hard ground. Where the road was on a level, drains were cut on each side of the intended line, by which, intersected with cross ones occasionally, the upper part of the moss became dry and tolerably firm: on this hurdles were placed, either in double or single layers, as the case required, 4 feet broad and 9 feet long, covered with heath; on these was laid the ballast, and the method was fully successful. Longitudinal bearings, as well as cross sleepers, were used to support the rails where necessary, and the whole was thoroughly drained. In the cutting, the whole had to be accomplished by drainage entirely. Longitudinal drains, about 2 feet deep, were cut on each side of the intended line of railway, and when by this means the upper surface of the moss had become dry, about 12 or 15 inches in depth were then taken out, as in an ordinary case of excavation; the drains were then sunk deeper, and another portion taken out when dry, as before; and thus, by alternately draining and excavating, the depth required for the railway was attained, which in some instances was 9 feet, the embankments being as high as 12 feet. The only advantage in favour of these operations was, that the surface of the moss was higher than the surrounding country, which partially assisted the drainage; but when it is considered that, from the nature of the ground, an iron rod would sink by its own weight, it must be confessed that such an undertaking as carrying a railway along, under, and over such a material, would never have been contemplated by an ordinary mind. In a smaller moss, which had also to be crossed, and which was about 20 feet deep, although an embankment of only 4 feet high was required, the clay and gravel tipped amounted to as much as would form one 24 feet high on ordinary ground."

(1) Lecount. "Practical Treatise on Railways," 1839.

In districts where stone is plentiful, the method of forming embankments and cuttings, shown in Figs. 1864, 1865, may be economically adopted. The embankment, or lower part of the cutting, is faced with rubble-work with a batter sufficient for its stability. On the Leeds and Selby line this facing to the embankments has a curved batter, the chord line of which forms an angle of 67° 30′ with the horizon. These embankments must be provided with strong parapets P,

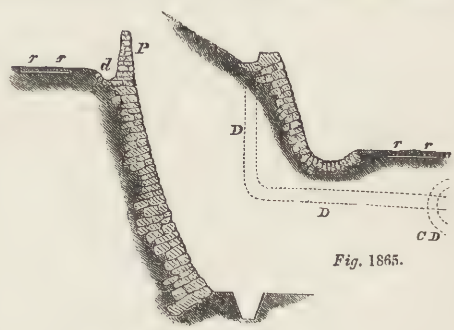


Fig. 1865.

Fig. 1864.

to prevent the train from falling over in case it should run off the line *r r*. When this occurs on the edge of an embankment formed of soil, and sloped at 2 to 1, the train would probably be arrested by sinking in the yielding material, which would evidently not be the case in embankments faced in this manner, with steep sides. In this method there is much economy in the amount of earth-work to be embanked, and in the width of land required; it also gives great facility of drainage and ensures stability. An open longitudinal drain or channel *d* being formed behind the parapets, and made to communicate with vertical or oblique channels formed on the face of the stone-work, conducts all the water to the toe of the embankment, whence it is readily withdrawn by side ditches. The slope of the earth-work above is also efficiently drained by a longitudinal channel D D behind the top of the facing, connected either with channels on the face, or perpendicular drains behind, with cross drains leading into the centre one C D, as shown in Fig. 1865.

The effectual drainage of the artificial works connected with a railway is of the utmost importance. The failure of many earth-works is to be traced to that secret and insidious enemy, water. Whenever about the works it is even suspected to exist, it should be traced to its source and diverted from slopes and adjoining surfaces. Beneath embankments every stream should be intersected, and every field, ditch, or other natural or artificial water-way, should

be connected with drains and culverts, for the safe and effectual conveyance of water from the work. The size of the culvert must of course depend on the quantity of water to be removed: it must be built in before the embanking is commenced, and be left for some weeks at least to consolidate before it is covered in. Good drainage is also necessary for embankment walls: retaining walls are liable to fail, from the saturation and consequent swelling of the earth behind them.

The method of forming tunnels will be noticed under a separate head. [See TUNNEL.]

Bridges and Viaducts.—Having, in our article BRIDGE, entered into full details respecting the construction of various kinds of bridges, it is not necessary to go into the construction of railway bridges and viaducts, although many of them present peculiar features, such as cast-iron *girder* bridges, the girders being laid from one abutment to the other, and supporting a platform of flag-stones, iron plates, or planks of wood. When the railway passes over such a bridge, six ribs or girders are used, 4 of which sustain the rails, and the other 2 the parapets, a light flooring of iron plates being constructed between the girders. This arrangement gives great strength, and supersedes the necessity for ballast, thus reducing the depth or thickness of the bridge to a minimum. In order to preserve the straightness of the railway, *skew* bridges are required at points where the railway intersects any existing communications at an oblique angle. Hence, in crossing such a road by a skew bridge, the communications over and under the bridge form unequal angles with each other. Many beautiful examples of brick and masonry-work are afforded by these ingenious structures.

The Britannia tubular bridge is fully described under BRIDGE. Another structure, equally remarkable in its way, is the *high-level bridge* at Newcastle-upon-Tyne, which forms the junction between the York and Newcastle, and the Newcastle and Berwick railways. This bridge was projected by Mr. Hudson, and designed by Mr. Robert Stephenson: it extends from the castle-garth on the north, to the high ground on the south side of the river. There are two roadways, one level with the castle-garth, for carriages and foot-passengers, and the other at an elevation of 22 feet above it. The carriage-road is 1,380 feet in length on a straight line. The bridge is 112½ feet from high-water line to the top of the parapet, and the roadway is 80 feet above the water. Six arches, each of 125 feet span, form the bridge,—the piers upon which they rest being of masonry, and the arches, pillars, braces, and transverse girders, of iron. The bridge-piers are nearly 50 feet by 16 feet in thickness, and in extreme height are 131 feet from the foundation, having an opening in the centre through each. They are erected on piles, which pierce the bed of the river, about 50 feet on the north side, and 20 on the south. The land-arches of the bridge diminish in altitude from the foundation upwards, corresponding with the steep bank of the river. The roadway for vehicles beneath the railroad is suspended from the great arches which carry the line; "and it is scarcely possible to imagine a more interesting or beautiful sight than it presents, with the huge span of the arches diminishing in perspective, and the opening at the furthest end of the bridge, showing only like a bright spot in the distance. The pillars, which carry the road, add greatly to the picturesque effect, and the multiplicity of column-ribs, transverse and vertical braces, produces such a combination of beautiful lines, as is seldom seen."[1]

We cannot quit this part of our subject without offering a remark on the extraordinary number of bridges and viaducts which occur in British railways. It was ascertained in 1847 that, for every mile or railway constructed up to that time, from 2 to 4 bridges had been built, many of them not mere single-arch bridges, but viaducts of hundreds of feet in length, and of great height, solidity, and cost.

The permanent way.—When the top surfaces of the embankments, bridges, and viaducts, and the bottom of the cuttings, have all been made to correspond with the intended level of the line of railway; or, in other words, when the *formation level* has been produced, the construction of the *permanent way* may be commenced. The permanent way includes a surface-covering of *ballast*, in which the sleepers are to be embedded: if the sleepers are laid transversely to the direction of the railway, they support chairs for carrying the rails; but if the sleepers are laid longitudinally, the rails are bolted down at once upon them without the use of chairs, and with the intervention of a piece of tarred felt, or of vulcanized India-rubber only. Provision must also be made for communicating between one line and another by means of crossings and turnplates, &c., for the passage of engines and carriages.

The ballasting, which should be from 18 to 24 inches in thickness, consists of very various materials, such as can be most readily and cheaply procured. Those in common use are burnt clay, burnt marl, rock marl, gravel, broken sandstone and lias, oolite-stone, &c. Loam does not afford a good ballast, but a mixture of chalk and flints is good, or a mixture of sand and broken stone; gravel and broken limestone form a good binding material, but gravel alone, or gravel and sand, or broken stone alone, does not bind well. Sand is very objectionable as ballast; it is raised up by the wind or by the draught occasioned by the velocity of the train, settles among the bearings, and gets between rubbing parts, cutting and wearing them away in a very remarkable manner. Cinders, or small coal, are used as ballast, where these materials are abundant. Where stone is plentiful, the whole line is sometimes pitched transversely with thin stones, and on this a bed of broken stone is spread for ballast, after Telford's plan for common roads.

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(1) "Our Iron Roads, their History, Construction, and Social Influences." By Frederick S. Williams. 8vo. London. 1852.

(2) Probably so called in contradistinction to the *temporary way* which is laid down in the first instance to facilitate the construction of the line.

The foundation of the permanent way is now formed of timber. Formerly, as noticed in our historical sketch, blocks of stone were laid down, either square with the railway or diagonally, for the reception of the chairs for holding the rails; but the weight of the passing train tended to thrust them asunder, and thus to disturb the gage of the line. The weight of the blocks was also found to disturb the stability of bridges and other constructed works. Timber, therefore, again came into general use, and is now preferred. It is first prepared by kyanizing, or impregnating it with certain saline substances, a process which is said to confer on soft wood the durability of oak. Timber is used for the cross sleepers of sufficient width to support a pair of chairs, as in Figs. 1866, 1868, or it is used in continuous longitudinal lengths,

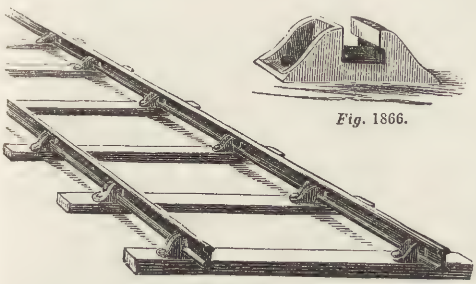


Fig. 1866.

Fig. 1867.

to which the rails, formed with bottom flanges for the purpose, are at once bolted, as in Fig. 1869, without

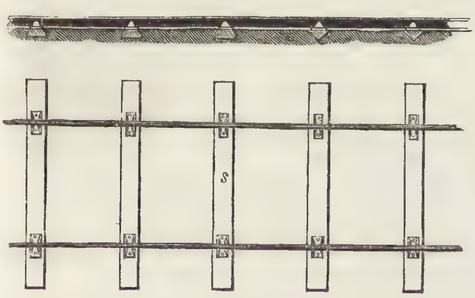


Fig. 1868

the intervention of chairs. These longitudinal timbers are connected by cross ties, halved or dovetailed

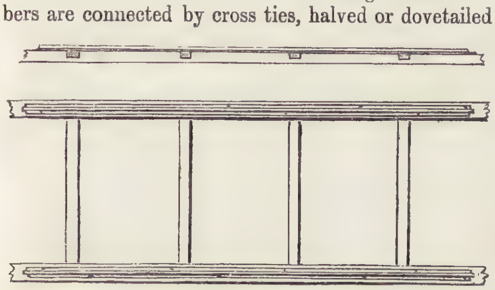


Fig. 1869.

into them. The continuous bearings were adopted by Brunel for his wide or 7-feet gage, but they have also been applied to many narrow gage lines.

For the 4 feet $8\frac{1}{2}$ inch gage the cross sleepers *s* are half round logs of beech, Scotch fir, or larch: each log is from 7 to 9 feet in length. On the South Eastern Railway the sleepers are of Baltic fir, cut from square baulks, each being divided diagonally into 4 triangular sleepers. They are laid with the right angle downwards, and thus present as large a surface for the chairs as the half baulks, and offer great facility for packing the ballast. See Figs. 1874, 1875. The distance between the cross sleepers should be some aliquot part of the length of the rail: it should not exceed 3 feet 9 inches, unless a very heavy section of rail be used. With a 15-feet rail the distance of 3 feet is often allowed, and is said to give greater steadiness and equality of motion; and in some cases 2 feet 6 inches has been adopted for a light rail and a small chair. Taking all the variations at present adopted, rails are laid on supports at 3 feet; 3 feet 6 inches; 3 feet 9 inches; 4 feet; and 4 feet 6 inches asunder.

Various sections of rails are shown in Fig. 1870. The

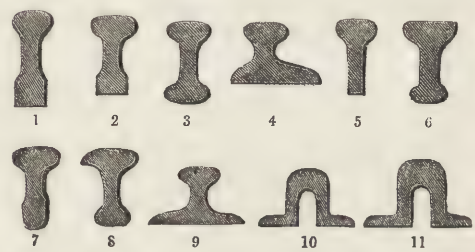


Fig. 1870.

double ┳ rail, No. 3, is a very common form on many railways with the 4 feet $8\frac{1}{2}$ inch gage. The single ┳ section, No. 5, is also used on several lines. Variations of these two forms are shown in Nos. 1, 2, and 7. In some rails, such as No. 8, the top surface is curved to correspond with the tire of the wheel. Bridge-rails, Nos. 10 and 11, are used with longitudinal sleepers, to which they are bolted by bolts passing through the lower webs or flanges. Nos. 4 and 9 are a combination of the ┳ rail with the broad base of the bridge-rail, and also admit of being bolted down on longitudinal sleepers. The other rails are supported in iron chairs, Fig. 1866, to which they are secured by means of wooden keys, Fig. 1871, or other means. Fig. 1871 is the chair of the North Western and other lines where double ┳ rails are used. The space for the rail is straight on one side, but curved inwards on the other. The flange of the rail enters into this curved

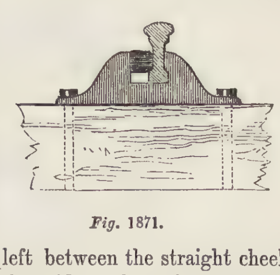


Fig. 1871.

recess, and the space left between the straight cheek of the chair and the other side of the web of the rail, is occupied by the wooden key or wedge driven in until the rail is firm in the chair. After dry weather the keys shrink and become loose, and require a few blows with a mallet to tighten them. This inconvenience is remedied by compressing the wood before it is inserted, for which purpose the oak keys are steamed, shaped, and then forced through an iron

block 10 inches thick, containing 12 holes, each $\frac{3}{16}$ths inch smaller than the key, and tapering so as to admit the key before compression. The keys are forced through the block by the ram of a hydrostatic press. Some rails are rolled with a notch in the side, into which a ball-key or other projection is driven from the chair to prevent the rail from rising. This arrangement is shown in Fig. 1872. A cylindrical hole is made through one of the cheeks at such a height as will correspond with the position of the notch in the rail when supported in the chair. Through this hole a small iron ball is introduced; a split key is then driven through the hole in the cheek, and crossing the groove in which the ball is placed, forces it into the notch of the rail: the latter is thus confined in position vertically, but it has a longitudinal motion, adapting it to the varying dimensions arising from changes in the temperature.

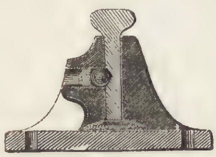


Fig. 1872.

Iron keys of various forms and arrangements have been introduced from time to time. Mr. Barlow uses hollow metal keys or pins, the elasticity of which is said to be advantageous.

The use of cast-iron chairs entails a loss from breakage during the fixing and keying. Wrought-iron chairs have been made by rolling the iron to the required form in lengths, and cutting up the lengths into chairs, and drilling and completing each one separately. Cast-iron chairs, however, are most commonly used, on account of their greater economy. The forms of these are very numerous, and are being continually increased. Mr. Barlow has introduced a cast-iron chair and sleeper, the effect of which is to produce great hardness and rigidity in the line, which he maintains ought to be the conditions of a railway, in opposition to elasticity. Fig. 1873 shows Mr. W. Brunton's combined cast-iron chair and sleeper. Fig. 1874 is a very common form of cast-iron chair, with the compressed wooden wedge and trenails: the adjusting gage used in the fixing is also shown. Fig. 1875 shews the mode of fixing the chairs, with the instruments used for boring the trenail holes. Mr. Dockray recommends that bridge-rails shall be laid down as shown in Figs. 1876, 1877: the rails are bolted at the joints, and on the intermediate cross sleepers, and where the rails meet there is a wrought-iron shoe: a uniform inclination or cant is given to the rails, and the mode by which they are fastened down is very secure. Figs. 1878, 1879, represent the form of chair and the arrangement of the rails at points and crossings. Fig. 1880 is a form of chair adapted to the double rail.

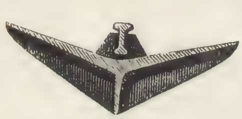


Fig. 1873.

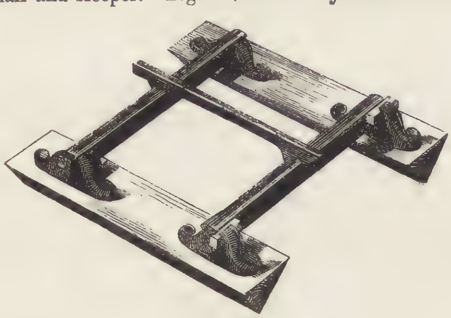


Fig. 1874.

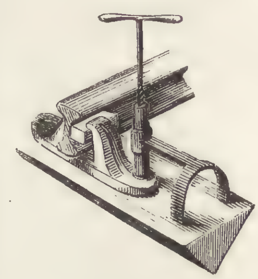


Fig. 1875.

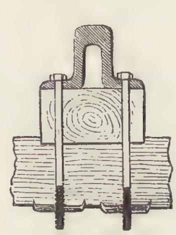


Fig. 1876.

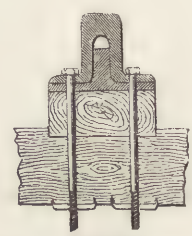


Fig. 1877.

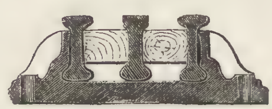


Fig. 1878.

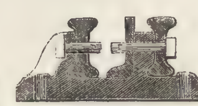


Fig. 1879.

In fixing the joints of the rails allowance must be made for temperature, which, in a range of 76° Fahr., will cause a difference in length, in a 15-feet rail, of about $\frac{1}{12}$th inch. A scientific friend informs us that he once saw on the Northampton line, where the ends of the rails butted too closely together, several yards of the railway raised up by the heat of the sun into a ridge about 2 feet above the level of the rail. The sleepers were torn up, and much damage done. The line had been opened for an excursion train, which had not yet returned, so that the line had to be hastily repaired, and in order to accommodate the increased length, the rails were laid down again in a curved form. In laying the rails some attention should be paid to the temperature, or too much, as well as too little allowance may be made for expansion. If too much allowance be made and the joints are square, the carriages are exposed to shocks and jolts. Concussion from this cause may be avoided by inserting a piece of wood between the ends of every two rails; the wood expands as the iron contracts.

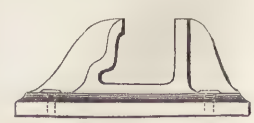


Fig. 1880.

The rapid increase of traffic upon the great lines of railway is strikingly illustrated by the increase in weight and strength which has been made from time to time in the permanent way. The rails originally laid down weighed 35 lbs. a-yard, and this strength was considered to be superfluously great: experience,

however, led to the replacing of these by others weighing 50 lbs. a yard; but even these were not found sufficient for the increasing traffic, and they were taken up and replaced by rails weighing respectively 62 lbs. and 65 lbs.; a further increase was made to 72 lbs. and 75 lbs., and the last rails that have been laid down have weighed 85 lbs. These changes have been and are being made gradually, so that on some of the railways at the present time the rails are of various weights, the lightest being 60 lbs., and the heaviest 85 lbs. per yard. For example, at the commencement of 1849, on 438 miles of railway, placed under the direction of the North Western Company, there were about 150 miles laid down with rails of 75 lbs. per yard, 100 miles at 65 lbs. per yard, and the remainder, in detached lengths varying from 50 to 70 miles, with rails varying from 60 lbs. to 85 lbs. per yard.

While the rails were thus being increased in weight, the engines and carriages were also made heavier. The first engine run upon the line, including its tender, weighed 7½ tons; but engines of this power were soon found to be insufficient for the traffic, and for the increased speed which this new form of power seemed to promise. As an increase of speed required an increase of power, and an increased power necessarily required an increased weight, engines were formed of the augmenting weights of 10, 12, and 15 tons. For some years the engines were made of gradually increasing weights, and at the present time one Company has upwards of 36 engines, weighing, with their tenders, about 40 tons each; and engines have been constructed of the enormous weight, including the tender, of 60 tons each.

So also with respect to the carriages: those first used on railways weighed from 3 to 3½ tons; their weight is now in some cases over 4½ tons. The goods-waggons have also been increased in strength and weight.

The increase in the traffic and in the speed, which have led to the increased power of the railway, has been far beyond the most sanguine expectations of the first railway directors and engineers. In 1831 the average speed of the passenger-trains was 17 miles an hour: this was gradually increased until, in 1848, it was 30 miles an hour; while the speed of the fastest trains which, in 1831, was 24 miles an hour, was in 1848, on the Liverpool and Manchester line, 40 miles an hour, and on the Grand Junction and the Liverpool and Birmingham, 50 miles an hour.

In 1837 the number of trains per day which arrived at and departed from the Euston Square station of the Birmingham line was 19; in 1848 it was 44. In 1831 the number of trains per day to and from the Liverpool terminus of the Liverpool and Manchester Railway was 26; in 1848 it was 90.

A corresponding increase also took place in the weight of the trains. In 1831 the average weight of a passenger-train, including the engine and tender, was 18 tons. In 1848 it exceeded 75 tons. In 1831 the average weight of a goods-train, including engine and tender, was 52 tons; in 1848 it varied from 160 to 176 tons.

Attempts have been made to ascertain the length of time that a rail will endure when subject to the usual traffic of a road. In this calculation accidents have been excluded; such, for example, as the failure of a rail at one of the joints; for as the metal for each rail is first made into a faggot, and then drawn out between rollers, the welds or joints of the faggotted pieces are apt to give way. The flange of a wheel will also in some cases come in contact with a ragged portion of the flange of the rail and tear it up; so that from these and other causes the rail seldom attains its natural age, or wears out in consequence of the abrasion from its surface of portions of the metal composing it by the passage of the vehicles. It appears from an inquiry made under the direction of the North Western Company, that rails laid down at the average weight of 70 lbs. per yard, exposed to a traffic equal to that which existed at the time of the inquiry, would have a duration of 20 years, after which the entire line must be relaid.[1]

In laying down the rails provision must be made for conducting the engines and carriages from one line to another, for which purpose *switches* and *turn-tables* are introduced at particular points. Switches are movable rails placed at the junction of two tracks, and capable of being adjusted so as to guide the train from the single track into either of the two tracks, or from either of the two into the single track. But before describing switches we will notice a contrivance for overcoming the inconvenience of a change of gage at one particular spot, as, for example, where the narrow gage already exists, and it is desired to connect it with the broad gage. The most economical plan is to lay a third rail outside the narrow gage line, at such a distance from it as will accommodate the broad gage carriages. This plan was adopted on that part of the Birmingham and Gloucester Railway which extends from Gloucester to Cheltenham. The Birmingham and Gloucester Railway is a narrow gage line, and the Great Western Company wishing to extend their line from Gloucester to Cheltenham, put down a third rail on the outside of the narrow line. At a short distance from the Cheltenham station of the Birmingham and Gloucester Railway they quit that line, and run by a branch of about a mile into Cheltenham. Fig. 1881 will explain the mode of arranging the rails at the point where the two lines separate, so that while the narrow gage trains pass along the old track, the broad gage quit the same, and turn off to the branch line without the attendance of any one. A B, C D are the rails of the narrow gage line, E F, G H those of the broad gage, G H being the continuation of the additional outer rail. The line of rail A F is cut through at E and at *p*, in order to allow the

Fig. 1881.

(1) An account of this inquiry, together with that of a similar inquiry in Belgium, is given in Dr. Lardner's "Railway Economy," 1850.

flanges of the wheels of the narrow gage trains to pass; and the rail C D is also cut through at *p*, to allow the wheels of the broad gage carriages to pass. When, therefore, a narrow gage train approaches the point E, the flanges of the wheels are kept close to the rail A B by the opposite rail C D, and they will evidently pass through the cut at E, the train moving in its course along the old line. But when a broad gage train arrives at the same point, the wheels are drawn over towards the rail G H by means of a *check* or *guard-rail*, *g r*, which acts on the inner side of the flanges of the wheels, by which means they are prevented from passing through the cut in the rail at E, and are made to move along the line A F, G H. Where the rails terminate at *p*, *g*, and *r*, the opening is enlarged in order that the flanges of the wheel may enter without difficulty.

For crossing from one line of rails to another a very common plan is, to lay down a short intermediate line with means for connecting or disconnecting it with either of the main lines. These means are afforded by the *switch* already referred to, and represented in Fig. 1882, in which A B, C D, are portions of the rails of the main line; *e f*, *g h*, portions of the short intermediate line: all these rails are fixed except the two rails *f i*, *k l*, called the *tongues* of the switch; these move on centres at *f* and *k*, their other ends are gradually brought to a point, a small recess being cut in the fixed lines at *i* and *l*, into which they fit. These tongues are connected together by a bar *b*, which keeps them at such a distance apart that when either of the tongues is in contact with the rail near it, the other is sufficiently removed from its rail to allow the flange of the carriage-wheels to pass between them. If it be desired to cause the train moving in the direction of the arrow to quit the main line and enter the branch, the bar *b* must be moved to the position shown in the left figure; but if the train is to continue its journey on the main line, the position shown in right-hand figure must be adopted. The switches are usually maintained in the position shown in the left figure, by means of a self-acting weight; but if the train is required to quit the line, a man must attend to move the switches into the position shown in the right figure. Two guard-rails *g r*, *g r*, are required to prevent the flanges of the wheels from striking against the point at the intersection of the two lines.

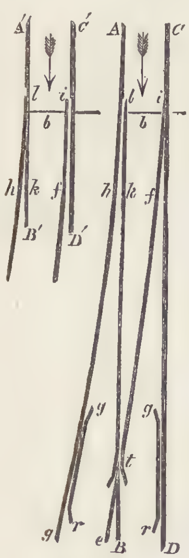


Fig. 1882.

Other methods of using switches are illustrated in Fig. 1883. When the traffic between two termini is not expected to be great, it is often desirable for the sake of economy to lay down only a single line of rails: but in such a case some contrivance must be made for allowing trains to pass each other. When the traffic is about equal in each direction, the passing-place may be arranged as in A B. The angles in this figure are made more abrupt than is desirable on a line of great traffic, where angles of more than 2° or 2½° should be avoided. A train coming along the single line A, proceeds by the lower

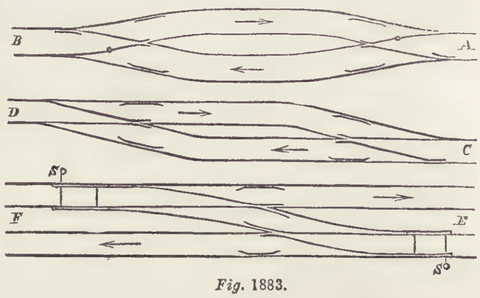


Fig. 1883.

track to B, while a train from B to A takes the upper track. Switches such as those already described are used at the points A and B, and being always passed through in the same order they are made self-acting. The arrangement C D can be used without any switch, the rails being cut through at the proper points, (as already explained in the case of Fig. 1881,) for the reception of the flanges in changing the direction from the single to the double line of rails. E F is a crossing for occasional use, the switches being worked by hand at the points *s s*.

One form of apparatus for moving the switches is shown in Fig. 1884, in which *r* is the rod attached to the rail, corresponding to *b b*, Fig. 1882, and also shown at *s*, Fig. 1883. This rod is hinged to a lever L at *n*. The lever moves on its centre at *m*, so that

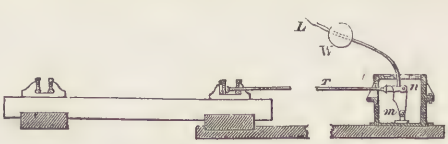


Fig. 1884.

when the lever is moved into or beyond the vertical, the rail to which *r* is attached will evidently be made to fall into the notch of the other rail. The weight W is intended to keep the lever, and consequently the switch, in the position in which it was left by the pointsman. It is very important to attach a signal to the post containing the lever apparatus for moving the switches. The signal may consist of a coloured disk of wood, or stretched canvass, so arranged that when its broad surface is placed in the direction of the coming train, the engine-man may know that the switches are in the right position for passing; but if the edge of the signal is towards him, he may then have an opportunity of slackening his speed or stopping until the proper adjustment has been made.

The turntable is a contrivance for moving a *single* carriage at a time from one line of rails to another.

It consists of a circular platform of timber or iron, supported on rollers and turning upon a centre without much friction, even when loaded with a considerable weight. The best construction of turntable adapted to six-wheeled carriages is illustrated in the following figures. Fig. 1885 shows a quarter plan of the top of the table and a quarter plan of the moving apparatus and fixed framing forming the base and casing of the table. Fig. 1887 is a cross section of the moving apparatus, and Fig. 1886 a side view of one of the latches by which the moving table is secured in each of its positions. r r are solid rails of

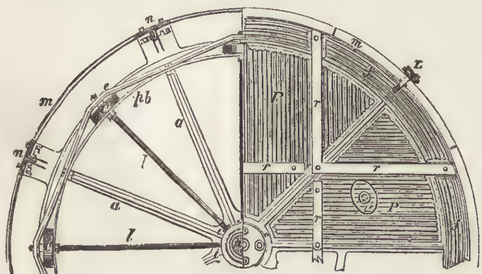


Fig. 1885.

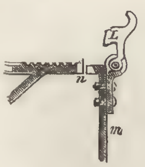


Fig. 1886.

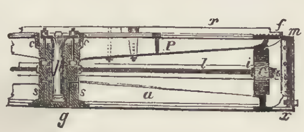


Fig. 1887.

wrought-iron fixed on the lid so as to correspond with the gage of the line, and forming 2 sets of rails or tracks crossing the lid at right angles to each other. The covering plates P P, which form the lid of the table, are of cast-iron corrugated on the upper surface, and resting in fillets on the cast-iron top framing ff. The lower framing, also of cast-iron, is furnished with arms a a, a bearing rim b b, and a hollow central boss s s. The upper framing is also perforated in the centre at c c. The movable top framing is supported by resting near the periphery on 8 cast-iron conical rollers C C, which turn upon the bearing-rim b b of the lower framing. It is also supported at the centre by bolts passing through the rim of a strong wrought-iron centre-pin p, turning in a gun-metal step g, supported in a socket k, which is held in the lower framing s s. The interior of the socket and of the central hole in the top frame is truly bored to fit the turned surface of the pin p. The rollers C C are held in their places by means of rods l l, screwed in wrought-iron rings i, and passed through a light framing formed of a ring of flat iron c, and of a continuous bar e of angle iron. The bar and the ring being bolted together, the ring i fits a shoulder formed on the socket k. The bearing rings of the upper and lower framings are accurately planed to fit the turned surface of the conical rollers. The casing consists of 8 segmental pieces m m, bolted together through the meeting flanches n n, and bolted also to the ears x x cast in the lower framing. The latch L is fastened by a pin to a small bracket bolted to the casing; four of these latches are thus fixed and are dropped into notches n, Fig. 1886, for the purpose of retaining the table in each of its positions. At v is a man-hole for giving access to the interior, for the purpose of oiling the rollers, &c. An unyielding foundation must be provided, or the cast-iron tables will be broken under the heavy weights placed upon them. In some cases a foundation is formed by constructing a well of brick-work, on the rim of which and on a central pier the table is fixed. In other cases the central pin is much extended in length, and the periphery is supported by stout bars fixed in a jacket revolving on the lower part of the long centre pin.

Turntables are useful for removing a single carriage from one line to another, and for this purpose they are often preferred to crossings and switches, because they occupy so little space. Fig. 1888 will show the method of using them. Supposing a carriage w is to be transferred from the track A to the track B, it is rolled upon the turntable at T, and the catches which hold the table being raised, the table with the carriage upon it is turned a quarter round, into the position shown by the dotted figure. The carriage is then rolled upon the turntable T′, which being in like manner turned a quarter round, the carriage is in the proper position w' for being moved to the track B. By this arrangement

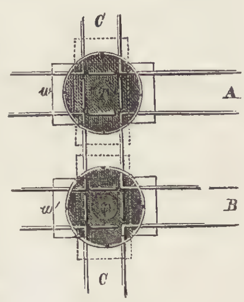


Fig. 1888.

carriages may also be removed to a cross track, as at C. The houses in which locomotive engines are kept, are often made octagonal, with 8 tracks radiating from a large turntable in the centre.

The limits of our space will not allow of much further detail respecting the permanent way. It should be properly fenced in with some of the ordinary kinds of fencing, or with stone walls in places where stone is abundant. Near stations brick or stone walls should be used, or the fence may consist of posts and battins.

The drainage of the permanent way must also be carefully attended to. For this purpose gullets are commonly cut across the ballasting for the purpose of leading the surface water into the side ditches or drains. Central longitudinal drains of rubble work, or of perforated tiles, are also sometimes formed in the cuttings and embankments: these drains communicate by means of cross-drains from 10 to 25 yards apart, and are formed much in the same manner as the open side drains. Through the entire length of the railway, there should be 4 parallel water-courses, 2 on each side. The tops of the slopes of cuttings should be protected by a fence and a mound, and outside these should be a field-drain for the adjacent land. At the feet of the slopes there should be drains for the water from the banks and from the surface of the railway. Drains should also be provided at the bases of embankments for carrying off the water from the railway and from the surface of

the banks, and parallel drains should be formed outside the fences. The surfaces of slopes are drained by V-shaped channels, as already noticed.

The stations and the termini should be arranged according as the passenger and goods traffic is large or small. On approaching the stations the two lines are in some railways made to diverge from each other so as to bring them close against the platforms, one of which serves as the departing place, and has the booking-offices, &c., contiguous to it, the other being the arrival platform, in the immediate vicinity of which are the refreshment rooms, &c. In other railways the rails go straight through all the stations. If the station be an intermediate one, both platforms will be used as arrival and also as departure platforms. At each terminus the space behind the 2 lines should be wide enough for 3 or more spare lines of rails, to hold carriages of all classes, horse-boxes, carriage-trucks, &c. Access from the main lines to these spare lines is obtained by switches, and by one, two, or more rows of turnplates, one row being placed across each of the extreme ends of the stations, and another intermediate, so that first, second, and third-class carriages may be introduced at any part of the train. The spare lines are connected with the main line by means of switches, the tongues of which admit of being wholly removed, except when in actual use, in order to prevent an arriving train from running against the points.

The construction of the locomotive engines will be given under Steam. The railway carriages scarcely require description. They are of large size, and the bodies are made to project over the wheels. No danger arises from this arrangement, because the evenness of the line, the low build of the carriages, and the great weight of the iron wheels, axles, and framing, prevents them from overturning. The great speed at which they are moved, and the shocks to which they are subjected, require them to be strongly built; and the fact that many of these ponderous vehicles, heavily laden, are linked together, requires the introduction of an elastic apparatus, which comes into play both at starting and at stopping the train. The traction must also be elastic, in order that the engine may not have to overcome the inertia of the whole train at once. For these purposes various contrivances have been made, the most common of

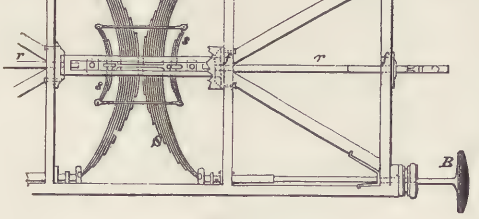


Fig. 1889.

which are shown in Fig. 1889, which represents the ground plan of a passenger-carriage, the body being removed. The frame which is outside the wheels is on lapped springs, which rest, by means of brass bushes, or bearings, on the ends of the axles, which are extended beyond the wheels, and are accurately turned for the purpose. B B are buffers or disks of wood or metal covered with cushions, attached to the ends of long rods, which pass through the frame and along the sides to the ends of the long springs S S, which are so formed as to move towards each other when pushed by the rods, but are prevented by stops on the frame from moving in the opposite direction. As the centre admits of sliding backwards and forwards, both springs are acted on by an impulse from either end. As all the buffers in a train are of the same width, and at the same height, they come in contact when, in consequence of a sudden stoppage, the carriages run closer together, and the jerk is thus imparted to the springs S S, the elasticity of which allows of sufficient motion to prevent any sensible shock to the carriage or to the passengers. The apparatus by which the carriage is drawn forward consists of rods *r r*, which pass through the frame at *f f*, and are connected with the small springs *s s*, which also act together, the centre of *s* pressing against the cross-bar of the carriage-frame as an abutment when the pull is in one direction, and against the centre of the other spring when the pull is in the other direction. The connexion between the different carriages may be a jointed bar of iron, which is disconnected by the removal of a pin; or by a peculiar kind of screw, which draws the carriages so close that their buffers come in contact. Chains are also sometimes used.

Atmospheric Railway.—The idea of employing the pressure of the atmosphere as a motive-power on railways has excited considerable attention, and led to many costly experiments. The atmospheric railway appears to have failed as a commercial speculation, but as some of its mechanical details are ingenious, it requires notice in this place.

We may suppose the crude idea of the application of atmospheric pressure as a motive-power to be as follows:—Suppose a large pipe to be laid down on a road, a mile in length, and that at one end of this pipe were placed an air-pump for withdrawing the air, and at the opposite end a piston, working accurately in the pipe, with a rope a mile in length attached to the piston, at one extremity, and to a train of carriages at the other. On pumping out the air from the pipe, the atmospheric pressure upon the piston would drive it along the tube, and the carriages would be drawn after it. But under this supposition, the carriages at the commencement of the experiment are a mile from one end of the tube, and 2 miles from the other end. In order to get rid of the long rope, it was desirable to arrange the apparatus in such a way that the piston and the carriages might travel together, much in the same way as the short tube, or pencil-holder inside a pencil-case travels with the outer tube or ring, which admits of being slid backwards and forwards by the fingers. For this purpose it was proposed to employ pipes with side-openings for attach-

ing a connecting-rod to the piston and the carriages; and it was supposed, that on covering this slit or opening with a rope, the air within the tube could be sufficiently rarefied for the required purpose. This proved to be a failure, but Messrs. Clegg and Samuda patented an arrangement which we are about to describe.[1] Their first experiments, on a large scale, were tried on a portion of the West London Railway at Wormwood Scrubbs. A series of cast-iron pipes, 9 inches in diameter, and half a mile in length, were laid down, and although the pipe and the rails were not in good order, yet on a gradient of 1 in 115, and with a surplus pressure on the piston of about 9 lbs. to the square inch, a load of goods weighing several tons was propelled at a rate exceeding 20 miles an hour, and in some of the experiments a speed of 30 or 40 miles an hour was attained.

The success of these experiments led the Government to advance a loan to the Dublin and Kingstown Railway Company, to enable them to construct a line on the pneumatic principle from Kingstown to Dalkey, a distance of about $1\frac{3}{4}$ miles. The line was ready for passenger-traffic at the end of 1843.

In this railway the vacuum-pipe was about 15 inches in internal diameter; it was of cast-iron, and was laid down, in the same way as the large water mains, between the two rails of the railway. After the pipes were cast, a cutter was passed through them in the direction of their length: they were then raised to the temperature of melting tallow, and a mop dipped in that material was passed through them, and being followed by a wooden piston, the inside became coated with a thin surface of tallow, which soon acquired great hardness. This was found to be an excellent surface for the piston to travel against. On the top of the tube was a narrow opening extending the whole length, closed by a valve V V, Fig. 1890, so as to render the tube air-tight. This valve was a con-

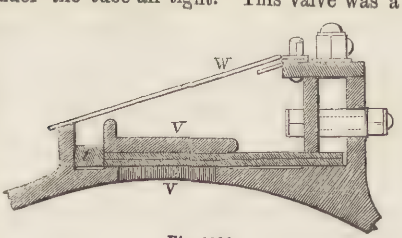


Fig. 1890.

tinuous flap of leather, on the upper and under sides of which plates of iron were riveted, the inner surface of the lower plate formed to the curve of the pipe, the upper plate and the leather being made a little wider than the opening or slot, and extending over it on each side. This continuous valve was hinged on one side to a projecting rib, and the other edge fell into a groove *t* containing a composition of wax and tallow, which, when melted, sealed up the pipe, and made it sufficiently air-tight for the working. A flap, called the *weather valve*, W, protected the apparatus from the weather. The piston contained within the tube was furnished with a rod 14 or 15 feet in length, to which were attached rollers R, Fig. 1891, for opening the air-tight valve behind the piston as it advanced along the pipe. The piston was

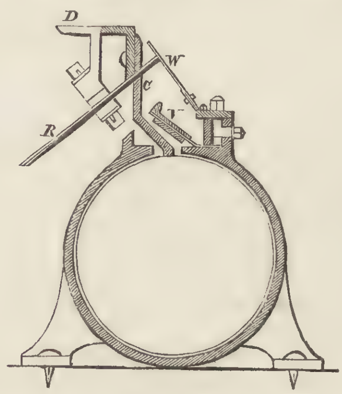


Fig. 1891.

connected with the first carriage, or *driving-car*, by means of a *coulter* C: to the driving-car was attached a copper vessel, several feet in length, heated with coke, for the purpose of melting the wax and tallow when the valve had been pressed down by the apparatus.

The tractive power in the pneumatic railway depends, as already stated, on the *difference* of pressure before and behind the piston. The sectional area of a piston 15 inches in diameter is about 176 inches. If the air in the tube in front of the piston be rarefied so as to produce a pressure of 10 inches of mercury, then the ordinary pressure of the air on the other side of the piston, which on an average is equal to about 30 inches, will be $30-10$, leaving a working pressure of 20 inches. Now a pressure of 30 inches of mercury is equal to about 15lbs. on the square inch [see AIR]; that of 20 inches is equal to 10lbs., so that the working pressure in this case is $176 \times 10 = 1760$lbs.

It will be understood, then, that the train of carriages moved on rails as in the ordinary railway; but between the rails the tube with its enclosed piston was situated; and that an air-pump worked by a stationary steam-engine, exhausted the air in the tube in front of the carriages. The speed of the train would evidently be in proportion to the rapidity with which the air could be pumped out. It was found that an exhaustion of 15 inches could be produced in about 2 minutes, and that a speed of 50 or 60 miles an hour could be produced.

The action of the apparatus will be better understood with the assistance of Fig. 1892, in which the rollers for opening the air-tight valve are shown. The piston P is supposed to be travelling in the direction of the arrow: as it advances, the two small rollers *r r* lift up the air-tight valve, which, when the coulter C has passed, is allowed gradually to fall into the groove again by the corresponding rollers r' r', and is firmly pressed down into its proper position by the upper roller *n*. The long heater H follows,

(1) It is stated that Papin, more than a century ago, suggested this mode of travelling. In recent times schemes have been proposed by Lewis, Vallance, Medhurst, and Pinkus. According to Mr. Vignoles, it was Medhurst who, about the year 1812, first suggested the right idea of connecting the body in the pipe or tube, directly acted on by the atmospheric power, with a carriage moving on the outside.

melts the wax *t*, Fig. 1890, and reseals the pipe: C is the connecting arm or coulter, and W is a counter-balance weight for the piston. The seat for the conductor is shown between the carriage wheels, and in

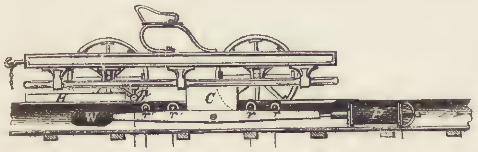


Fig. 1892.

Fig. 1891 is also shown the roller R for opening the weather valve W.

In the line which we have taken as an example of the working of the atmospheric railway for a short distance, the carriages were attached to the piston at Kingstown, the air was pumped out by means of a double-acting pump with 5½ feet cylinders at Dalkey, worked by a stationary engine: the piston soon began to move, the driving-car or piston-carriage opened the sealed valves, and as the car passed, these valves were pressed into their proper channel by the apparatus described, and the heater followed and sealed the valves, and when the train had arrived at its terminus, the valves along the line were in a fit state for the passage of another train. The return journey was performed by descending the incline (which had a gradient of 1 in 115, and in some places was even steeper) from Dalkey to Kingstown by the action of gravitation only, and as the piston was not required for the purpose, it was taken out of the tube and placed outside.

In the year 1845, a portion of the atmospheric railway from London to Croydon was opened for traffic. This line was constructed on the eastern side of the locomotive line of the Brighton Company, and to prevent it interfering with that line at the point where it diverges from Croydon, it was conducted over that railway by a timber viaduct, to which it rose on each side by a slope of 1 in 50. These slopes were generally ascended without any difficulty, although on some occasions the power was not sufficient for the purpose. In the summer of 1846 the iron tube, by exposure to the sun, frequently became so hot as to melt the composition which sealed the valve, so that the vacuum could not be maintained, and the line had to be worked by locomotives. Other lines were constructed on the atmospheric principle, but the difficulty of commanding a sufficient amount of rarefaction for working purposes, gradually led to the abandonment of the system. Several ingenious suggestions were made to remedy the inconvenience. One, by Mr. Hallette, was, to make the coulter a thin flat bar, passing vertically through a slit in the upper part of the atmospheric tube, and to keep this slit closed everywhere, except where the coulter was passing, by means of two continuous air-bags or hose placed in a collapsed state in grooves in the top of the pipe, and then inflated with air so as to press against each other. This certainly is the most simple of all the valves that have been proposed for the atmospheric railway tube, and its action may be illustrated by drawing a paper-knife between the closed lips. Other plans have been proposed, among which may be mentioned a *magneto-atmospheric railway.* It is described in the Mechanics' Magazine for January, 1846.

The Rope Railway.—The great expense of locomotives and their enormous weight, have led to the use of stationary engines, which have been employed to draw the train by means of a rope. There is no doubt that stationary engines are more economical than locomotives, but the difficulty is, to provide a rope capable of withstanding the tractive force and the friction. For steep inclined planes the rope is used for drawing up the train. In some cases the rope is endless, and is conducted along both tracks by grooved pulleys, to keep it off the ground, and is passed at each end round a wheel placed below the level of the road, the upper one of which is turned by the engine. The plan of working a railway by what are called *tail-ropes* was adopted on the London and Blackwall railway. A stationary engine was erected at London and at Blackwall, each of which turned a grooved wheel, to which a rope of nearly 6½ miles, or double that of the railway, was attached. A train starting from London was arranged with the Blackwall carriages foremost, and then those for the intermediate stations in the order in which they are required to stop. A signal being given, the Blackwall engine commenced winding up the rope, by which the train was drawn forward at the rate of 20 or 30 miles an hour. On approaching the first station, the carriage intended to stop there, which was by this arrangement made the last of the train, was released from the rope by opening a pair of pliers which connected it thereto, and applying a brake to check the acquired momentum of the carriage. The rest of the train proceeded without interruption, a carriage being dropped behind on arriving at the stopping stations. The Blackwall engine, in addition to drawing the train, had also to unwind the rope from the barrel of the London engine, so as to prepare it for moving the train back again when reloaded. In the return journey, the various carriages left behind in the first transit were attached to the rope, and were all moved towards London at the same time, but, of course, they arrived at London in different times according to the points at which they were dropped. When they were all collected together at London, they were in the proper order for another journey. The same arrangements as the above were applicable to the two tracks, each track having a similar apparatus, and being worked alternately in both directions. In working this line it was found very difficult to keep the ropes in good order, and the passage of the ropes over the sheaves produced much noise. Wire ropes succeeded best, but these were not satisfactory. At length the rope system was abandoned, and the line was worked by locomotives, which continue in use.

In concluding the important subject of railways, which we have extended to the full extent of our limits, we have regarded a railway as a great engineering work, and therefore confined our details chiefly to those of construction. Information respect-

ing the general economy and management of the line must be sought elsewhere.[1]

ROCK- or ROCH-ALUM. See ALUM.

ROCK CRYSTAL. See QUARTZ—SILICA.

ROCK SALT. See SODIUM.

ROCKET, a cylindrical case of pasteboard or iron, attached to one end of a light wooden rod; the case contains a composition which on being fired causes it and the rod to be projected through the air by a force arising from the combustion. The use of rockets is to communicate signals between parties separated by distance or by darkness, and they have been employed in trigonometrical surveys, and for ascertaining the difference in longitude between two places. Rockets are also used in warfare. In signal rockets the upper part of the case, containing the powder which produces the projectile force, has united to it a conical case for the composition which by its explosion produces the stars of light that form the signal. Rockets of this kind may weigh from from $\frac{1}{2}$ lb. to 2 lbs. A 1 lb. rocket is $1\frac{5}{8}$ inch in external diameter, the length of the cylindrical case is $12\frac{2}{8}$ inches, and the length of the conical head $3\frac{1}{8}$ inches. The rod is attached to the rocket on one side near the base: its length is about 8 feet, and its thickness about half the diameter of the rocket. The cylinder is filled with a mealed composition consisting of saltpetre in the proportion of 4 lbs. 4 oz., sulphur 12 oz., and charcoal or mealed gunpowder 2 lbs; the composition for producing the stars consisting of saltpetre 8 lbs., sulphur 2 lbs., antimony 2 lbs., mealed power 8 oz., isinglass $3\frac{3}{4}$ oz. The isinglass is dissolved in 1 quart of vinegar, after which 1 pint of spirit of wine is added, and the mealed composition is mixed with the liquid into a stiff paste. The composition for burning is rammed into the rocket-case, but a conical space is left along the axis for access of air to facilitate the combustion; and at the *choke* or neck of the rocket, where the rod is attached, are apertures, by one of which the rocket is fired. The use of these holes is to prevent the case from bursting, the flame escaping by them into the atmosphere; and the pressure of the gaseous matter suddenly liberated against the opposite extremity impels the rocket forwards or upwards, just as a gun recoils on being fired. In the case of a gun, however, the recoil is instantaneous on account of the extremely rapid combustion of the gunpowder; but the rocket composition is so compounded as to produce a comparatively slow combustion, and so long as the composition continues to burn the impelling force is maintained. The use of the rod is to guide and steady the flight of the rocket. Rockets of from 1 to 2 inches in diameter have been known to ascend vertically to the height of about 500 yards; and those from 2 to 3 inches diameter, 1,200 yards. The times of ascent vary from 7 to 10 seconds, and the rocket has been seen at distances varying from 35 to 40 miles.

ROLL or ROLLER, a cylinder of iron, wood, paper, &c., used in the construction of machines and in several works and manufactures; but sometimes under other names. For example, the weaver in preparing his loom winds the threads or yarns on a large roll called a *beam*. [See WEAVING.] In the manufacture of plate glass a thick cylinder of cast brass, called a *running roll*, is used for spreading the glass over the casting table. [See GLASS, Sec. viii.] Rolls form an essential part of the machinery used in CALENDERING. Copper-plate and lithographic printing is performed at a *roll-press*. [See PRINTING, Sec. viii.] *Friction* rolls are two parallel circular plates of brass, about $\frac{1}{4}$ inch thick. Four or more solid brass cylinders are placed at equal distances round these plates, and work upon their own axes between them at right angles. Thus any pin working through these plates and brass must touch the rolling surfaces of the solid brass cylinders, by which the friction is greatly diminished. *Spherical* rolls are also used. See BRIDGE, Sec. vi. COINING, &c.

ROLLING MILL. See IRON, Fig. 1240.

ROOD, a quantity of land equal to the fourth part of an acre, and containing 40 square perches or poles.

ROOF. See CARPENTRY.

ROPE, an assemblage of several twists or strings of hemp, twisted together by means of a wheel so as to form a flexible and tenacious cord or band. The term is usually applied to all cordage above 1 inch in circumference made of hemp spun into yarns or threads, of a certain length; a number of these yarns or threads, according to the size of the rope, are twisted together into a *strand*. Three of these strands twisted or laid together is called a *hawser-laid rope*, and 9 of them a *cable-laid rope*. When the rope is made very thick it is called a *cable*, and when very small a *cord*.

Rope-making is an art which all nations seem to have practised from the earliest times. Various kinds of fibre have been used for the purpose, such as hemp and flax, tough grass, the husk of the coco-nut, the fibres of the wild banana, &c., and animal substances have also been used, such as strips of oxhide, horse hair and wool, and in our own day metallic wires have been twisted and plaited into cords and ropes of great strength and of various sizes.

Thongs of leather were used in the rigging of ships during many ages; and at the present time in some parts of the world ropes of considerable length and strength are formed by twisting thongs of leather.

(1) Dr. Lardner's "Railway Economy," already referred to, is full of valuable information, presented in a clear and useful manner, respecting the management and statistics of railways. With respect to the history and details of construction up to the year 1838, we must refer to Wood's "Practical Treatise on Railroads," &c. 3d edition, and to the article "Railway" in Hebert's Engineers' and Mechanics' Encyclopædia. This article is beyond 200 pages in length, and is abundantly illustrated. With respect to construction, a very valuable work has been published by Mr. Weale, entitled "The Practical Railway Engineer: examples of the mechanical and engineering operations and structures combined in the making of a railway." Illustrated by 50 large steel plates, containing numerous examples. Written for the Royal Engineers by G. Drysdale Dempsey, C. E. 4to., London, 1847. We have to express our thanks to Mr. Weale for his liberal permission to make use of this work. In Mr. Whishaw's "Railways of Great Britain," will be found a notice of the chief features of most of our lines, and the engineers of some of the principal lines have themselves published detailed illustrated descriptions of some of the works executed by them.

The ancient Romans are said to have made ropes by the twisting of vegetable fibres long before the time of Cæsar; and after the invasion of Britain by that people, they are said to have used our native rushes or *junci* for forming ropes. Some writers suppose this to be the origin of the term *junk* applied to old cables and worn-out ropes.

The superiority of the fibres of hemp to those of most other plants has caused them to be chiefly used in the manufacture of cables, ropes, cords, canvas, and sail-cloth. The cultivation, retting, &c., of hemp is described under HEMP. In forming a rope, as already noticed, the fibres are first spun into yarns, the yarns into strands, the strands into a rope, and the ropes into a cable. The shortness of the hempen fibres (about $3\frac{1}{2}$ feet being the average length,) requires this complex arrangement. If they were long enough to form a rope the most advantageous method of using them would be to lay the fibres side by side, and to secure them at the two ends. Each fibre would then bear its own share of the strain, and the strength of the bundle would be that of the sum of the strengths of the separate fibres. As a long rope could not be formed in this way, the ends of the fibres are secured by twisting so as to produce sufficient compression to prevent the fibres from sliding upon each other when a strain is applied; but in attaining this amount of compression by means of twist, the strength of the fibres is greatly deteriorated; this very compression acts as a constant weight on the strength of the fibre, and must be deducted therefrom before the available strength can be applied. Réaumur found that a small well-made hempen cord broke in different places with 58, 63, 67, and 72 lbs., its mean breaking weight being 65 lbs.; while the 3 strands of which it was composed bore $29\frac{1}{2}$, $33\frac{1}{2}$, and 35 lbs. respectively; so that the united absolute strength of the strands was 98 lbs., although the average real strength of the rope was only 65 lbs., thus showing a loss of strength from twisting equal to 33 lbs. Réaumur's experiments were made in 1711. The more recent experiments by Sir Charles Knowles give a nearly equal loss of strength by twisting. He found that a white rope of $3\frac{1}{2}$ inches in circumference broke on an average of several trials with 4,552 lbs.; while the aggregate strength of its yarns, 72 in number, was 6,480 lbs. (each yarn bearing about 90 lbs.); thus the loss was 1,928 lbs. or about 30 per cent.

The strength of ropes is sometimes calculated by the following rule:—Multiply the circumference of the rope in inches by itself, and the fifth part of the product will express the number of tons the rope will carry. Thus, if a rope be 6 inches in circumference, $6 \times 6 = 36$, the fifth of which is $7\frac{1}{5}$.

The weakening effect produced by twisting varies considerably among the fibres of the same rope according to their distance from the centre or heart of the bundle. If a certain amount of twist be given to a bundle of fibres, the outer fibres, occupying more space than the inner ones, will be strained more, and will act with less useful effect than the inner fibres, which will have to bear the greater part of the strain while the rope is being used. It will therefore be evident that if the fibres of hemp were twisted at once into a thick rope the outer fibres would be so much strained as to be of little or no use in contributing to the strength of the rope; but by first twisting the hemp into slender yarns, and a number of yarns into strands, and 3 of these into a rope, the strain is more equalized, and the important properties of length and strength are secured without too great a sacrifice of the strength of the individual fibres. There is also another reason why a rope could not be at once formed by twisting a bundle of fibres together. Such a rope when left to itself would immediately begin to untwist. This tendency to untwist is counteracted by twisting the fibres together in small portions and then combining them in such a way that the tendency to untwist in one part shall counteract that tendency in another.

Duhamel has endeavoured to ascertain the amount of twist that would produce the most useful effect. He made some ropes in which only $\frac{1}{4}$th the length of the yarns was absorbed in twisting instead of the usual proportion of $\frac{1}{3}$d. These ropes when used in shipping were found to be lighter, thinner and more pliant than those in ordinary use. Ropes made of the same hemp and the same weight per fathom, but twisted respectively to $\frac{2}{3}$ds, $\frac{3}{4}$ths, and ^{4}ths, of their component yarns, supported the following weights in two experiments:—

$\frac{2}{3}$ ds.	4,098 lbs.	4,250 lbs.
$\frac{3}{4}$ ths.	4,850	6,753
$\frac{4}{5}$ ths.	6,205	7,397

The result of these experiments led Duhamel to make ropes without twist, by placing the yarns together and wrapping them round to keep them together. The rope had great strength, but not much durability on account of the outer covering soon wearing away or opening at bendings, and thus admitting water, occasioning the yarns to rot. These *salvages* or skeins of rope yarns are, however, used for the tackle of great guns, and for some other purposes where great strength and pliancy are required.

Preparation of the yarn. Before spinning the hemp into yarn it is heckled or hackled for the purpose of separating and straightening the fibres. The heckle is formed of a number of straight steel prongs set in a board with the points upwards: they are of various sizes; the smaller heckles strip the hemp of its short fibres or tow, when the hemp is said to be *cropped*, and is used for fine work, or for spinning below the usual *grist*, as it is called, the usual grist being a rope 3 inches in circumference, with 20 yarns in each strand.

In the process of heckling, a quantity of hemp sufficient for spinning into one yarn 160 fathoms long is first weighed out, and the heckler, holding the fibres at one end, throws the bundle loosely over the points, and pulls it gently towards him: a number of fibres is retained in the heckle, and by repeating the process they are all retained. He then lifts up the whole bundle, and passes it again through the

heckle, the operation being assisted by the application of a small quantity of whale-oil to the points. The fibres, thus separated, and made tolerably parallel, are tied up into a bundle, Fig. 1896, called a *tow* of hemp, weighing about $3\frac{1}{2}$ lbs. Heckling greatly improves

Fig. 1893. Heckling Hemp.

the appearance of the hemp, converting the hard knotted mass, as shown in Figs. 1894, 1895, into a loose silky skein, Fig. 1896.

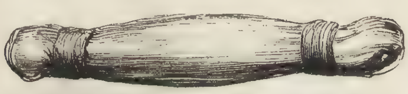


Fig. 1894.

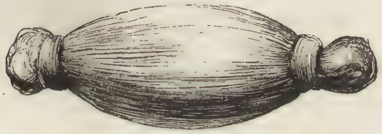


Fig. 1895.

Fig. 1896.

Spinning.—The fibres are spun into yarn in a long rope-walk of 600 or 1,200 feet, one end of which is called the *head*, or *fore-end*, and the other the *foot*, or *back-end*. At one end is a spinning-machine, Fig. 1897, consisting of 2 upright posts with a wheel between them, the band of which passes over several rollers or *wheels*, Fig. 1897, turning on pivots in brass holes, the pivots projecting and terminating in small hooks, so that by turning the wheel the hooks are made to revolve rapidity. Posts are arranged at equal distances on each side the walk, Fig. 1899, and between every pair of posts a rafter is extended across ; hooks are driven into this rafter for the purpose of supporting the yarns as they are spun.

The number of whirls in the spinning-machine (generally about 12) determines the number of spinners that can work together. Each spinner wraps round his body a bundle of hemp sufficient for the spinning of 1 thread of yarn, taking care that the *bight* or double of the fibres is in front, the two ends passing behind his back. He draws out from the face of the bundle as many fibres as the size of the yarn requires, and, twisting them between his fingers, attaches the bight to one of the whirl-hooks, while the wheel, being turned by an assistant, throws *twist* or *turn* into the fibres. The spinner holds in his right-hand a piece of thick woollen cloth, with one end hanging over the forefinger; with this cloth he grasps the fibres as they are drawn out, and presses them firmly between his two middle fingers, walking backwards all the time from the head to the foot of the walk, occasionally making a signal with his left-hand to the wheelman to turn fast or slow as may be required. He regulates the supply of fibres with his left-hand so as

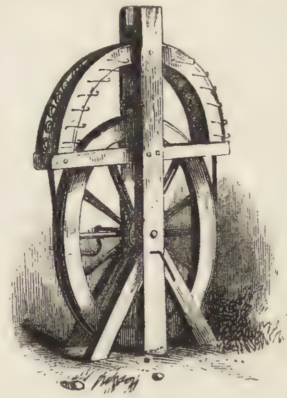


Fig. 1897.

Fig. 1898.

Fig. 1899. Spinning Rope Yarns.

to make the yarn of equal size, drawing back some if they enter his right-hand in too great a number, and putting forward more if the supply is defective. He does not allow the ends of the fibres to come near together, but distributes them in a kind of flat skein, so that the yarns may have a similar strength throughout. The thickness of the yarn depends on the quantity of hemp which passes through the spinner's hands in a given time, and on the rapidity with which the hook is made to turn. The spinner walks backwards at the rate of about 2 miles an hour, and as the yarn increases in length, he throws it over the hooks

on the under side of the rafters, which are placed 5 fathoms apart. When the spinner has got to the lower end of the walk, and his length of yarn is sufficient, it is detached from the wheel and fastened to a reel, the spinner holding the end of his yarn, for if let go it would untwist: as the reeler turns the reel the spinner walks slowly in, keeping the yarn equally tight all the way.

The spinner is paid 7*d.* for spinning 6 threads or yarns. This is called *one quarter's work.* A good workman will in one day spin 8 quarters, or 48 yarns, each yarn 160 fathoms in length; and as the spinner has to traverse the whole length of the walk twice for every yarn, once in spinning it out, and back again in reeling it in, he has thus to walk nearly 18 miles in the course of one day's work.

Rope yarns are commonly from $\frac{1}{12}$th to rather over $\frac{1}{8}$th inch in diameter; 160 fathoms of white, or untarred yarn, weigh from $2\frac{1}{2}$ to 4lbs.

When a number of spinners are *set-on* at the same wheel, each fastens his thread to a whirl, and they all proceed together down the walk; each man throwing his yarn on one of the hooks of each rail as he passes it. When they arrive at the foot, they join the ends of every pair of yarns and hang them over the post; and in order to be able to separate them, a piece of twine is tied by the middle to the first pair a little in advance of the post; the second pair is then put over the post, and a string is tied over them, and in this way every pair is tied in. This is called *nettling*. The spinners now *set-on* at the foot or *back-end wheel*, and spin up the walk. The forward wheelman having unhooked the yarns from the whirls of his wheel, and hung them over the posts, and tied them in pairs at the back-end, proceeds down the walk collecting the yarns from the hooks.

Rope-yarns are now in some places spun by machinery, as will be noticed further on; but we may here mention that, by the improved apparatus of Mr. Lang of Greenock, the hemp is completely heckled, and each fibre is laid at full length in the yarn instead of being doubled as in hand-spinning. These machine-spun yarns have a strength of 55 per cent. over hand-spun yarns of equal grist.

If the cordage is to be tarred, the process of *tarring the yarns* is now introduced. Tarred cordage is considerably weaker than untarred, but it is better calculated to resist the wet. It loses its strength gradually in cold countries, and rapidly in hot climates. According to Duhamel,[1] untarred ropes sustained a greater weight by nearly 30 per cent. than tarred ropes; and he states that white cordage, in constant use, is one-third more durable than tarred, that it retains its force much longer when kept in store, and resists the action of the weather one-fourth longer. Cordage, when only tarred on the surface, is said to be stronger than when tarred throughout. Messrs. Chapman, of Newcastle, have stated that the rapid decay of tarred cordage is due to the presence of the mucilage and of the acid of the tar, which they propose to remove by boiling the tar with water and concentrating the washed tar by heat until it becomes pitchy, restoring its plasticity before use by the admixture of tallow or oils.

Preparatory to tarring, the yarns are warped into a *haul;* that is, they are unwound from the reel or roller, and stretched straight and parallel, when 300 or 400 yarns are assembled in a large group or *haul*, about 100 yards long. This haul is dipped into tar heated to about 212° in a copper or tar-kettle, and is then dragged through a hole, called a *grip*, or *gage*, or *sliding-nipper*, which presses the tar into the yarn, and removes the superfluous portion. The tar must not be too hot, or the yarns will be charred; nor too cold, or they will be black; they ought to be of a bright brown colour. The proper temperature is judged of by the closing in of a scum over the surface of the tar.

The yarns either tarred or untarred are next twisted or *laid* into strands, the twist of the strand being in an opposite direction to that of the yarns, in order to counteract the tendency of the separate yarns to untwist, and that the yarns in their turn may counteract the tendency of the strand to untwist. The laying walk may be under the same roof as the spinning walk. It is provided with tackle-boards and wheels for twisting the strands, and stakes and stake-heads for supporting them. The tackle-board, Fig. 1900, for twisting large strands is fixed at the head of the walk; it consists of strong upright posts supporting a plank pierced with holes which correspond to the number of strands, generally three, of which each rope consists. Winches

Fig. 1900.

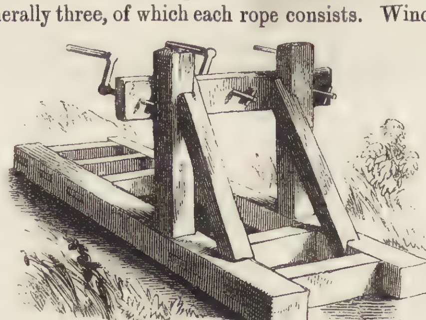


Fig. 1901.

or *forelock* hooks work through these holes. One of the smaller wheels for laying the smaller strands is shown in Fig. 1902; it is supported on a strong post at the head of the walk: the axes of the pinions are prolonged into hooks, and the driving wheel is worked by a winch. The strands are supported by beams or stake-heads placed at intervals along the walk; each stake-head, Fig. 1903, contains a number

(1) "Traité de la fabrique des manœuvres pour les vaisseaux; ou l'art de la corderie perfectionné." 4to. Paris, 1747.

of upright pins, between which the strands are placed. The yarns as they are run out for laying are first secured to posts at the head and foot of the walk, and as they become shortened by being twisted into strands they are afterwards attached to movable sledges, Fig. 1905, situated at the foot of the walk. The upper part of the sledge, called the *breast-board*, corresponds to the tackle-board, Fig. 1900. The sledge is loaded with *press-barrels*, *i.e.* old tar-barrels filled with clay, for keeping it steady, and iron weights are also used for the purpose.

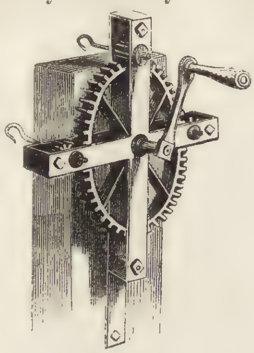


Fig. 1902.

Fig. 1903.

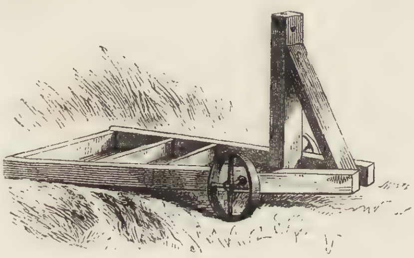


Fig. 1904.

Supposing now that the yarn is properly warped for laying into strands it is run out along the bearers of the laying walk, and the number of yarns required for the rope is counted out, and divided into three separate portions, each portion being placed in one of the divisions of the bearers, and hung upon the hooks of the tackle-board and sledge. The sledge is pulled backwards to stretch the yarns tight, and the press barrels are put on. The yarns are now examined to see that they are of equal length and properly stretched; the hooks at each end are now heaved round in a contrary direction to the twist of the yarn, and in this way the three bundles of yarn are formed into 3 strands. By the consequent shortening of the yarns the sledge is drawn forward some way up the walk. When the strand is *full hard*, or has enough *hard* in it, as it is termed, the twisting is discontinued; the sledge is moved forward to slacken the strands, and to allow of their being taken off the hooks.

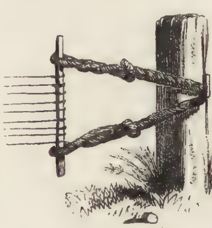


Fig. 1905.

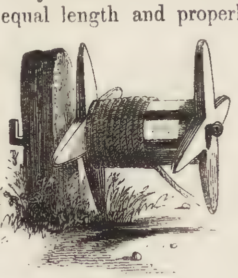


Fig. 1906.

The three strands thus formed are laid or twisted together into a rope; for which purpose they are attached to the middle hook of the tackle-board, and then placed in the grooves of a conical block of wood, Fig. 1907, called a *top*, through which passes a pin for the handles or *woolders* as they are called. A piece of soft rope called a *tail* is attached to each woolder by its bight in the middle, while the ends are used to secure the rope in laying the strands. Tops of various sizes are used, and when a top is of very large size it is supported on a sledge. Now the 3 strands being attached to a hook of the breast-board, and then continued along the grooves of the top as in Fig. 1909, the top is forced back as near the hook of the sledge as possible, and the men at the head again turn their hooks in the same direction as before. As soon as the sledge begins to move forward, the men diminish the load on the sledge, and turn the hook in a direction contrary to the former, by which means the top is forced forward; the 3 strands closing behind it as in Fig. 1908 form the rope. The reason for turning the single hook containing the ends of the three strands in a contrary direction to the three hooks to which the other extremities of the strands are attached, is to regulate the progress of the twists of the strands found their common axis, that the three strands may receive separately at their opposite ends just as much twist as is taken out of them in consequence of their being twisted the contrary way in being laid together. When the top is some way off from the sledge the tails are wrapped round the rope, and they by their friction prevent the top from moving by jerks and also enable the rope to close better. In this way a rope is formed by twisting 3 strands together. It will be seen that the strands unite into a rope on one side of the top, and are kept separate on the other side, and that as the rope is formed the top is gradually driven forwards. The motion of the top requires to be regulated so as to ensure equal hardness in the rope: the topman, therefore, before putting in the top, makes a mark across the strands of every beam: if, when the top reaches a beam the mark be above the bearer, the topman knows that the turning at the foretop has been too fast; if the mark be below, he knows that the turning has been too slow.

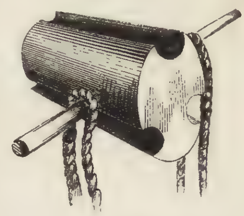


Fig. 1907.

Fig. 1908.

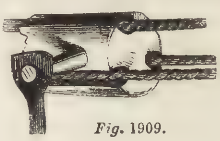


Fig. 1909.

In laying a very thick rope, the men may not be able to turn the hook of the sledge to which the strands are attached; but they are assisted by other

men, who apply woolders at intervals between the sledge and the top: the strap of each woolder is wrapped round the rope, and the pin is used as a lever to heave round the twist. The men at the woolders keep time in heaving with the men at the hook of the sledge; and in the case of heavy ropes the top sledge is used to support the rope.

In laying the strands it is necessary to vary the pressure at different parts of the process, and also the angle at which yarns take their position in the strands; the angle which the strands assume in forming a cable also requires attention. In making a cable of 100 fathoms, for example, the length of the strands should be 152 fathoms and should be laid at an angle of 27°; hard is given until each strand is shortened the length of 10 fathoms, when the angle must be 37°. In making the strands the sledge travels 24 fathoms, and the angle then made should be 32°. In laying the cable, the length of the strands thus formed amounts to 118 fathoms, and the angle when hard should be 40°. The length of the cable when finished is generally 101 fathoms; the strands entering with an angle of 35° while laying, and finishing at one of 38°.

With regard to the press-weights on the sledge: those for the strands of a 12-inch cable begin at 60 cwt., and when the length of 5 fathoms is attained, 10 cwt. is subtracted, and at $7\frac{1}{2}$ fathoms another 10 cwt. is removed; so that the *press*, when the strand is *hard*, is 40 cwt.: but if it lays well another 10 cwt. is removed for the remaining distance. In laying the cable, the press begins at 160 cwt.: this is reduced 10 cwt. at $1\frac{1}{2}$ fathom; another 10 cwt. is taken off at 2 fathoms, and when the cable is observed to lay well, another 10 cwt. is removed, leaving a press of 130 cwt. for the rest of the cable.

The twisting of *three* strands together in the manner described forms what is called a *hawser-laid* rope: this is called the *first lay*. The *second lay* is performed with *four* strands, producing what is called a *shroud hawser-laid* rope. The 4 strands are laid in the same way as the 3, and under the same conditions; but in order to render the rope solid, a *core-piece*, consisting of a few yarns, is run through the centre. The *third lay*, or *cable-laid* rope, consists of 3 hawser-laid ropes, each formed of 3 large strands, twisted or laid together into one gigantic rope or cable. This, however, is now seldom made, the chain-cable having taken its place [see CHAIN-CABLE]; but as cable-laid ropes are very hard and compact, ropes of no very great size are made in this way, if intended to resist the action of water.

Fig. 1910.

Where great pliability is required, ropes are formed by *plaiting* instead of twisting; as for clock-lines, sash-lines, and generally where ropes have to pass over small pullies.

Flat ropes, used for mining purposes, are formed of two or more small ropes placed side by side and united by sewing, lapping, or intertwining with thread or smaller ropes. Flat ropes are also formed by similarly uniting a number of strands of shroud-laid rope. In either case the component ropes or strands must be alternately of a right-hand and a left-hand twist, or the rope would not remain at rest.

The weight of cordage may be calculated by the following rules:—

For shroud or hawser-laid rope, multiply the circumference in inches by itself; then multiply the product by the length of the rope in fathoms, and divide by 420, the product will be the weight in cwts.

For cable-laid cordage, multiply its circumference in inches by itself, and divide by 4. The product will be the weight in cwts. of a cable 120 fathoms long; from which the weight of any other length may be deducted.

ROPE-MAKING BY MACHINERY.—About the year 1792 a rope-making machine, named a *cordelier*, was invented by the Rev. E. Cartwright, which does not appear to have attracted much notice until 1805, when it was partly incorporated into some very beautiful rope-making machinery invented by Capt. Joseph Huddart, which we are about to describe.[1] This machinery, in its most complete state, was introduced into the Royal Dock-yard at Chatham for the purpose of supplying the navy with ropes and the smaller cables, the large cables, which were formerly made at Deptford, having been superseded, as already noticed, by the introduction of chain-cables. By means of Captain Huddart's machinery the hemp is cleaned and combed, and divested of its loose splinters; the fibres are disposed in a parallel and uniform direction, and then spun into yarn with an equal degree of twist and tension: the yarns are then tarred, registered, and twisted into one uniform strand; these strands are twisted into ropes and cables by contrivances which maintain one continued strain in every stage, combined with a uniform tension.

The methods of forming the fibres into yarn are similar to those described under FLAX. The *heckling*, or *gilling-machine*, consists of a number of pointed wires, called *gills* or *heckle-teeth*, fixed in an erect position to an endless chain moving at a uniform rate. The rough hemp is spread out by a boy upon a feeding-trough into a loose bed, by the motion of which it advances in a broad uniform sheet towards the two rollers, which seize it, while the heckle pins, continually moving forward, comb and disentangle the fibres, and make them parallel. The stream of hemp being gradually drawn forward, at length escapes from the heckles, and is received between drawing-

(1) We are indebted for this description to a paper by Mr. John Miers, contained in the fifth volume of "Papers on subjects connected with the duties of the Corps of Royal Engineers." 4to. London, 1843.

rollers, revolving at different speeds, whereby the fibres are drawn out and compressed into a broad thin riband. It is next gathered by a guide into a narrower space, and compressed between other small rollers, which deliver the sliver thus prepared into a can. In a second machine two of these slivers are doubled into one, and, in a third machine, the doubled sliver is still further drawn out into a single and more uniform sliver.

The sliver thus prepared is received into a delivering can, and passed to another machine, called the *compressor*. This machine consists essentially of a solid metallic piston, sliding upon a square horizontal bar, with considerable resistance, by means of a spring. The filling-can, which is open at both ends, is slid over this piston, and held in its place between two fixed ends or caps, one of which is conical in shape, and one end of the piston, being also conical, corresponds to the inner surface of this cap. The end of the sliver is passed through a slit in this cap, and is then tied to the piston; by the revolution of the bar and can the sliver is then made to wind itself upon the bar, while at the same time it is compressed between the cone and the piston. In this way, by the accumulation of the yarn, the piston is gradually pushed forward; and when the can is filled with compressed sliver, the piston acts upon a rod which throws a forked lever aside, whereby the driving strap, which causes the winding bar and can to rotate, is shifted to the loose rigger, and the machine stops of itself. A boy then removes the full can, and places an empty one, and sets the machine at work as before.

The compressed sliver next passes through the spinning machinery, which of course does not differ in principle from the machines employed in spinning cotton slivers. Each spinning frame comprises 12 spindles, or spinning tubes, and 3 winding drums. The spindles are set in motion by a main shaft, upon which are fixed, at equal distances, 12 pulleys, in which endless cords work, that pass also in corresponding pulleys attached near the base of the 12 vertical spindles. Each spindle is accompanied by a can of compressed sliver, and the can is made to revolve with a certain speed, in order to give a preparatory degree of torsion to the sliver. It receives a further degree of twist by passing through the hollow tube, the point of which is furnished with clipping jaws, which grasp the thread; and while it is being twisted with great velocity, it is subjected to a considerable degree of tension and compression by being passed over and under 4 pulleys in succession. From these pulleys the twisted sliver, now called yarn, passes to 1 of the 3 winding drums. Each of these drums receives 4 yarns from as many spinning tubes, and the yarns are prevented from getting entangled with each other by being passed separately through corresponding holes in the register plate of a regulating bar. In order that the yarns may be equally wound upon all parts of the drum, they are made to move in succession to the right or left, while being wound from one end of the drum to the other, and back again. This is accomplished by giving to the regulating bar a right and left horizontal motion, through a space equal to the length of each winding drum.

From the drums the yarns pass to the winding machine, the object of which is two-fold; first, to separate the 4 yarns previously coiled together upon each drum, and then to wind them a second time upon distinct bobbins or reels; and, secondly, by the same operation to reverse the *lay* of the yarns, so that, in going through the subsequent process, each may follow the same course in which it was spun. If this precaution were not adopted, the ends of the fibres would be drawn out, and the strands would be rough and unsightly.

One of the most important of Captain Huddart's inventions is the *register*, the object of which is to keep all the yarns separate from each other before being twisted into strands. For this purpose they are wound upon reels turning freely upon spindles, in such a manner that each is allowed to contribute the exact length of yarn, and no more, in the uniform twist required in making a strand. The yarns being so arranged, the end of each is passed through what is called a *register plate*. This is a metal plate, of a somewhat hemispherical form, pierced with as many holes as there are yarns, which holes are arranged in concentric circles, care being taken so to apportion the number of yarns in each circle that they dispose themselves in a compact form, with as few vacancies as possible, round one common central yarn. The distance, or diameter of each concentric circle around the adjoining one in the register plate, is such as to allow the several series of yarns to arrange themselves at a determined angle, in order to give them a proper position to enter into the general twist now about to be given to the strand; this done, the body of yarns united for the purpose is received into a cylindrical tube, wherein they are made to undergo a certain degree of torsion, by which at the same time the whole is compressed into a compact body: by this means the strand has a truly cylindrical figure. Lastly, a certain amount of *hard*, or greater degree of twist, is given to the strand, thereby increasing the angle of the outside series, with the view of compensating for the stretching of the yarns and the compression of the strand.

Another improvement is, the adaptation of the registering apparatus at a short distance from the tube, and the winding of the strand so formed upon a drum, subjecting it, in the interim, to a considerable tension,—a contrivance that ensures one common uniformity of twist and diameter from one end of the strand to the other, which could never be attained to the same extent while the strands were made on the ordinary rope-grounds, where they remained extended a length of nearly 1,000 feet, offering, from several causes, a variable degree of elasticity, and an uncertain amount of tension in different parts of the strand.

Captain Huddart further considered that the body of yarns of which a rope is constituted can never be brought together in a cold state without leaving con-

siderable vacancies, into which water must enter while the rope is exposed to the weather, and engender decay from fermentation caused by the included moisture. This led to the invention of the *warm register*, in which the yarns, being immersed in heated tar, undergo the requisite amount of compression and torsion while still warm.

We now proceed to describe these inventions in detail. We have traced the yarn up to that stage in which it may at once be formed into strands; or if intended to be tarred, the process just alluded to—the warm register—now comes into operation. The tarring-house is separated from the other buildings by a second partition, in order to guard against accidents from fire. In the centre of the apartment is a fire-place for heating the tar, protected by an arched enclosure of brickwork. The boiler, or tar-kettle, K, Fig. 1911, is covered by a casing, or funnel *c* W, for carrying off the fumes through the roof into the air. The number of yarns required for the strand being settled, that number of reels *r r* is arranged in several series upon a vertical square frame of wood F F. The ends of all the yarns from these reels are brought in a converging direction across the apartment to a square iron plate *p*, perforated with a number of round holes, each yarn passing through a separate hole: the ends are then brought, in a parallel direction, obliquely downwards to another similar plate *i*, fixed in the middle of the tar-kettle, and are then directed horizontally towards and through another plate *i*, perforated in like manner; then, upwards obliquely through a fourth similar plate *p*, and they afterwards pass horizontally to a

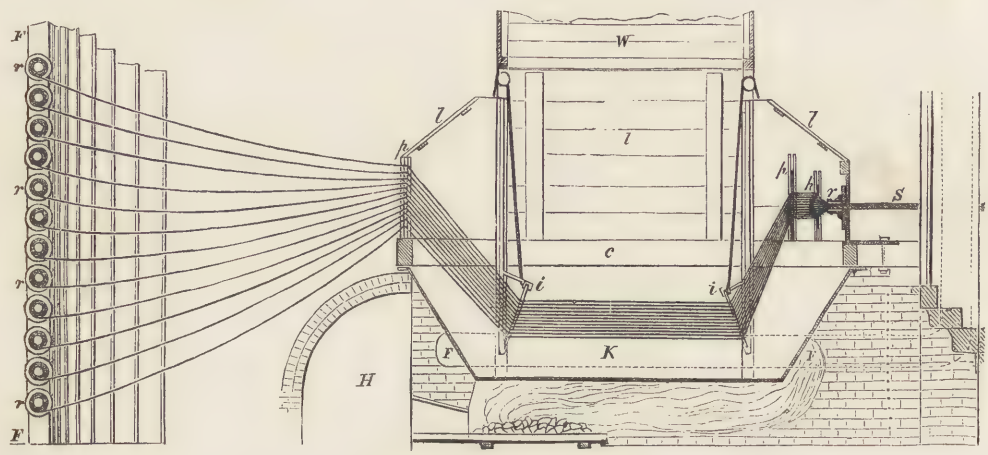


Fig. 1911. TARRING THE YARNS.

convex circular plate *k*, which is pierced in like manner with round holes, through which the yarns are severally passed, all converging thence into one common point, through the register plate *r*, in which is a cylindrical tube of metal, fixed by its collar to a framework. All the yarns thus brought together within this tube here undergo a preparatory amount of twist and pressure, and the strand S thus formed is conveyed to the *register machine*, in the adjoining apartment, in order to undergo further twisting and compression. The temperature of the tar is kept at 212° Fahr.: a thermometer is placed in it, and the fire regulated by its indications. The surplus tar adhering to the threads is first scraped off in passing through the plates near the register tube, and is further pressed out by the compression of the united yarns in the register tube. *l l* are lids to the tar kettle: H is the stoke-hole, and F F the flue.

By this process, the tar is made to cover the fibres, and fill the interstices of the yarns, thereby agglutinating them into an elastic substance, almost impenetrable by water or damp, and well adapted for hawsers, standing rigging, and other kinds of cordage exposed to the weather. But it is found that in proportion as it resists wet, it becomes rigid, and less applicable to running rigging. For the latter purpose, therefore, the *cold register* is used; that is, as the yarns are tarred, they are wound upon reels; and these being fixed in a framework, the yarns are passed through the holes of the register plate, into a register tube, where the united yarns are forced into a strand, and twisted as before.

This register tube consists of two compressing plates, or dies,—the lower one fixed in a stout framework, and the upper one working vertically in a grooved guide. The upper die is brought down, so as to form a hole of the required size, and is held in its position by a weighted lever. While the strand is passing between these dies, the superfluous tar pressed out is received into a can below.

The machine for twisting the strand while in the register tube, besides giving the requisite degree of twist to the united bundle of yarns, while the compression is being effected in the register plate, draws forward the strand thus formed, and winds it in regular coils upon a drum. This registering machine consists of a square frame of wood *a a*, supported horizontally upon two fixed gudgeons, *b b*, Fig. 1912, upon which this frame, together with the apparatus contained within it, is made to revolve. The strand enters this frame through one of the gudgeons upon which the frame revolves,—this gudgeon being made hollow for the purpose,—and the strand is kept tight

by being made to pass under and over two pulleys *o o* in succession, in its way to the winding drum. These two pulleys are mounted on spindles *n m*, to which motion is given by the following contrivance:— To the hollow gudgeon is fixed a pinion *j*, into which a toothed wheel *k* works; this wheel is fixed on a short spindle *l′*, supported on proper bearings; at the other end of this short spindle is a bevel pinion *l*, which works another bevelled wheel *m*, attached to the spindle that carries one of the pulleys, over and under which the strand is coiled. At the lower part of this same spindle is a toothed wheel *m′*, which acts upon a similar wheel *n′*, attached to the spindle which bears the other pulley. Now, it will be evident, that as the whole frame revolves, these pulleys are set in motion also; the revolution of the frame imparting twist to the strand, and the motion of the pulleys dragging it forward through the register tube.

The same motion which effects these operations is also made available for winding the finished strand upon the drum. The pulley spindle *m* projects through the framework, and to this projecting end is fixed a small mitre pinion, working into a similar pinion *p′*, attached to a spindle *p* on the outer side of the frame. To the other end of this outer spindle is a bevelled pinion *q′*, which works into a bevelled wheel *r′*, fixed to the end of the axis of the winding drum *s*. Now, a little consideration will show, that, as the frame revolves, the two tightening pulleys and the winding drum have each their own distinct revolutions. As the coiling advances, the diameter of the winding surface, or drum, goes on

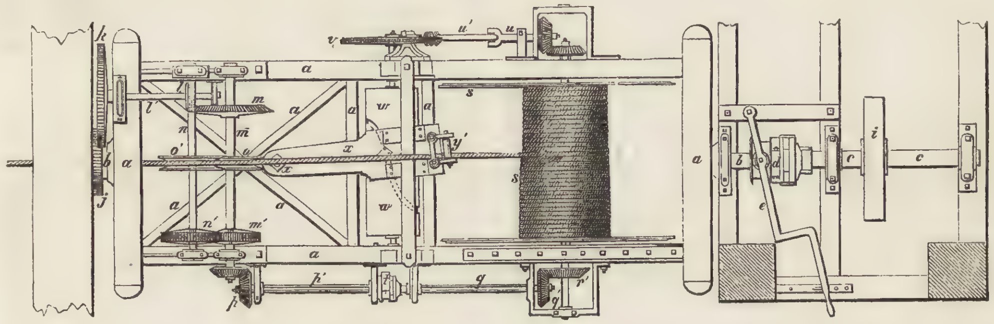


Fig. 1912. HUDDART'S REGISTERING MACHINE.

enlarging, which would give an increased amount of tension to the strand, and subject it to an unfair strain. This, however, is prevented by an ingenious contrivance:—the outside spindle *p′ q*, which transmits motion from one of the pulley pinions to the drum, is divided into two equal parts at *t*, and united by means of a clutch, which has two frictional surfaces, by which means, whenever the drum has a tendency to overwind the pulleys, and thus exert an unfair strain upon the strand, one of the frictional surfaces slips upon the other, by which means the drum is stationary for a small space, while the pulleys continuing their motion, the strain upon the strand is relieved, and the drum moves round as before. There is also an ingenious contrivance for making the strand pass from one side to the other of the drum, so as to produce a regular series of uninterrupted coils. On the opposite end of the drum is a mitre pinion, which acts upon another similar one, attached to a short spindle, which is furnished at its extremity with a universal joint *u*, acting upon the forked end of an oblique spindle, which bears an endless screw, working into a toothed wheel *v*; this wheel is fixed upon the end of a spindle placed across the frame, which spindle carries a wooden roller *w*, which is thus made to acquire a rotatory motion, in a determined ratio to the revolution of the frame. Upon this roller is a long, oblique, endless groove, in which a stud is made to act; this stud projects from under the face of the guide frame *x*, to which it is attached. It is, therefore, clear, that in proportion as the drum revolves the roller receives from it a very slow rotatory motion; while this, in its turn, communicates to the guide frame a corresponding reciprocating action, alternately from side to side. In order to produce a regular coil upon the drum, this reciprocating motion must, of course, be varied in proportion to the diameters of the different kinds of strands; and this is provided for by substituting for *v* another toothed wheel, of different diameter. The strand is held constantly in a position at right angles to the direction in which it is coiled upon the drum, by means of two vertical rollers, and a horizontal one *y′*, at the extremity of the reciprocating guide frame. Connected with this machine is a lever, and to the gudgeon *b* is attached a shifting friction clutch *d*, so that the machine can be set going or stopped in an instant by connecting or disconnecting it with the shaft *c c*, which carries the toothed wheel *i*, which in its turn is acted on by gear-work, moved by the steam engine. There is also a contrivance for measuring the length of the strand as it comes into the registering apartment, by passing over a pulley of a certain diameter, which sets in motion a series of wheels, forming a kind of reckoner or counter, that expresses upon a dial the number of fathoms that have passed over the pulley. An index being set to the number required, an apparatus causes a bell to ring when the number of fathoms has been prepared, whereupon the attendant stops the machine. The strand now prepared is wound off the drum upon a loose reel, so that when transferred to the drum of the apparatus in the next process it may become

reversed, end for end, in which state it is ready to undergo the operation of being formed into rope by the laying machine.

In the formation of a good rope, it is essential that each strand of which it is constituted should receive an equal degree of torsion and tension, and this is effected by means of a separate apparatus for each strand, while the results of these distinct actions are at the same time united by a general combination of these motions into one centre. This partial apparatus is called a *spole-frame*, and as it is usual to form a rope of three strands, three spole-frames are combined together in this laying machine. The steel engraving is an elevation of the rope-laying machine. Fig. 1913 is a section in plan through the upper portion of the

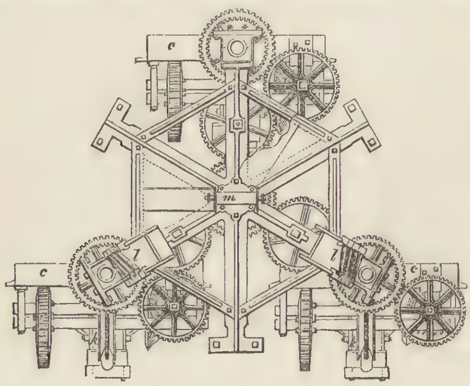


Fig. 1913. PLAN OF TOP.

machine; and Fig. 1914 is a section in plan through the lower part, being a section through the shaft, &c. This machine is supported on a fixed central pillar *a*,

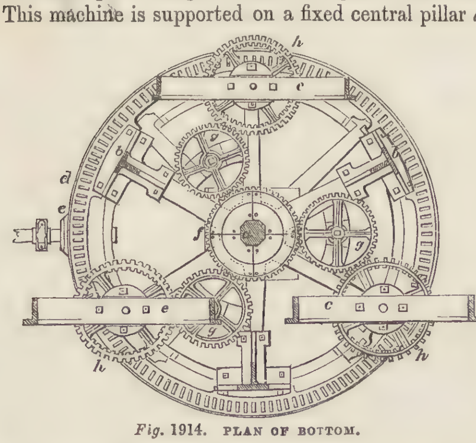


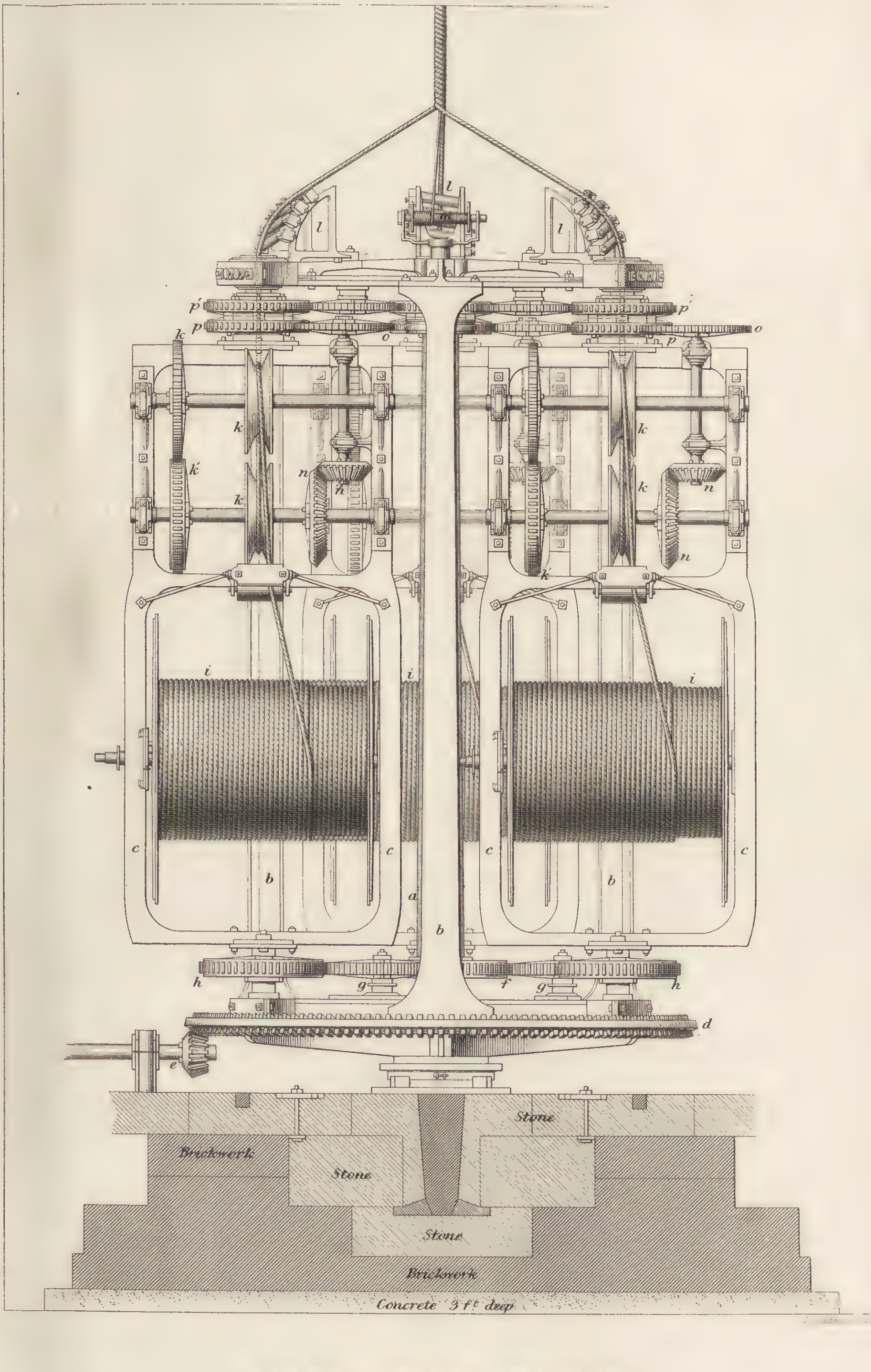
Fig. 1914. PLAN OF BOTTOM.

the foot of which rests in a solid foundation of stone and brick-work. This pillar, just above the masonry, has a circular bearing turned upon it, and has also a strong flange on which the lower portion of the revolving framework rests. The summit of the pillar has another circular bearing, on which the upper portion of the framework revolves. The lower part of this framework consists of a large iron bevel-wheel *d*, having a series of wooden cogs with their faces downward upon its outer rim, which is strengthened within by a broad expansion which carries 3 vertical iron columns *b*, while its arms converge into a strong central bush or nave, by which the whole framework turns steadily round the central pillar. The 3 columns *b* support a horizontal iron frame above, which consists of 6 converging arms united by cross stays, and a central bush, by which it works steadily on the upright pillar *a*. This open cage, or framework, carries the 3 spole-frames, each of which bears its own separate strand. The rotation of this framework is effected by the working into the cogged rim of a toothed bevel pinion *e*, which is driven by the steam-engine. The spole-frames are of cast-iron, in the form of a parallelogram, having in the centre of their transverse top and bottom plates, firm gudgeons; the lower gudgeons work in 3 steps formed on the internal rim of the wheel *d*, in intermediate spaces between the vertical columns *b*, while the upper gudgeons, which are hollow, work in plummer blocks fixed to the arms of the upper framing, so that each spole-frame thus has a gyratory motion of its own, which it acquires by means of a series of cog-wheels both in the upper and lower parts of the general framework. *h* is a cog-wheel fixed upon the lower gudgeon of each spole-frame; an intermediate toothed wheel *g* is fixed upon one of the arms of the frame *d*, and works into *h* as well as into the head central cog-wheel *f*. It will be seen, by reference to Fig. 1914, that the great frame is urged round by its cogged rim *d*, so that each intermediate wheel *g* being made to revolve about *f* thus acquires, not only a general revolution round the central pillar, but a distinct rotatory action about its own centre, which gyratory motion it communicates in an opposite direction to the wheel *h*, and consequently to the spole-frame *c*.

In the lower compartment of each spole-frame, in fixed bearings, is a drum *i* containing the proper length of registered strand, and in order to preserve a due strain upon it so as to prevent it overwinding, clutch or friction-bands are adapted on one side of each drum, by which any degree of retarding force can be applied by merely tightening a screw.

During the action of the machine each strand is wound off its drum by 2 pulleys *k* to which an equal amount of motion is imparted by 2 cog-wheels *k'*, which are made to turn by the bevel-wheel *n* working into the bevel pinion *n'*, while this is impelled by a toothed wheel *o*, and this again is acted on by a cog-wheel *p* fixed on the upper gudgeon of the spole-frame, and *p* is set in motion by another system of gyratory wheels similar to that in the lower part of the framework. The 2 toothed-wheels *p* and *p'*, on the upper gudgeon of the spole-frame, are of equal diameter: *p'* communicates the impulse from the gyratory system of wheels, while *p* permits the action of *o* around *p* during the revolution of the spole-frame, which would otherwise be impeded by the intervention of the intermediate wheel that forms part of the sun and planet motion about the central pillar.

The 3 strands being thus gradually and equally drawn over the pulleys *k*, now pass upwards through the upper gudgeon of the spole-frame, made hollow for the purpose of their curving over a series of rollers *l*, which are fixed, inclined in a varying manner to



ROPE. LAYING MACHINE.

prevent the strands from slipping off, now all unite into one common centre, and each, by the peculiar revolution of its own spole-frame having received its proper amount of torsion, they are at this point, by the general rotation of the entire frame, all twisted together into a rope, which is carried up to an apparatus where it is subject to an equal strain.

The cordage made for the use of the British Navy is distinguished by a coloured worsted thread, introduced into the centre of each strand; and every combination of strands or rope is also distinguished by a simple yarn, of peculiar make, laid in its centre, thereby affording a mark of distinction from every other rope. For the purpose of introducing this, a reel *m* of the intended yarn is fixed upon the end of the vertical central pillar *a* immediately under the newly-forming rope, which as it proceeds carries within it the distinguishing yarn from the reel.

At the time when the rope-making department of Deptford Dock-yard was in activity, three of these rope-making machines were in use: they were of various sizes, the smaller one being used for cordage of ordinary size, the intermediate one for larger rope and hawsers, the more powerful one being chiefly used for cables and hawsers of large size. It was calculated that this large machine would make about 2,000 tons of cordage per annum of 313 working days, taking the mean average of cables at from 14 to 24 inches, and hawsers at from 7½ to 12 inches. The second machine would make about 700 tons of cordage per annum, taking the mean average of cable-laid rope at from 8 to 16 inches, and hawser-laid from 5½ to 7½; while the smaller machine would prepare about 300 tons of cordage in the same time, taking the mean average of cablets at from 5½ to 7½ inches, and shroud-laid from 3½ to 5. These three machines were able to provide sufficient cordage to answer the demands of the whole British Navy.[1]

These details will suffice to explain the principles upon which rope-making machinery is constructed. Since the date of Huddart's invention many patents have been taken out for rope-making machines. The visitors to the Great Exhibition must have been surprised and delighted at the apparently complicated but easy motions of Mr. J. Crawhall's machine by which yarns were spun into strands, and the strands into a rope which was wound upon a reel as fast as it was formed. In the *Mechanic's* Magazine, No. 1,473, is a detailed account accompanied with wood engravings of some rope and cordage making machinery communicated from abroad, the patent for which is taken out in the name of Mr. Brooman and is dated 2d April, 1851.

In the manufacture of ropes, as described in this article, we have considered hemp as the only material used. Other kinds of vegetable fibre have been used with advantage. It appears from some experiments made at Paris with ropes of hemp and of the *aloe* from Algiers, that the latter bore a strain of 2,000 kilogrammes, while a hempen rope of equal size bore only 400. Ropes have been formed of *long wool*, but they have only about one third the strength of hempen cordage of the same size. The fibres of hemp intermixed with *threads of caoutchouc* give a rope of superior strength and elasticity; such a rope has been used with advantage with the grapnel or anchor of a balloon, arresting the machine without the usual unpleasant jerk when the grapnel catches.

Ropes of *iron wire* have been used with advantage in mines. They appear to have been introduced about 1831 into the silver mines of the Hartz mountains, and were found so superior that the flat and round ropes of hemp were soon superseded. From a statement by Count Brünner to the British Association in 1838 it appears that these ropes were nearly equal in strength to solid bars of the same diameter, and equal to hempen ropes of 4 times their weight. One of them had been in use for upwards of two years without any perceptible wear, although a common flat rope performing the same work would not have lasted much more than one year. The diameter of the largest rope in ordinary use is about 1½ inch: it is composed of 3 strands, each containing 5 wires of 2 lines in diameter. Care is taken that the ends of the wires may be set deep in the interior of the rope, and that 2 ends may not occur near the same part. In using these ropes they require to be wound on a large drum, not less than 8 feet diameter, and be kept coated with tar to prevent oxidation. The use of the wire rope economises horse power.

Patents have at various times been taken out in this country for the manufacture of wire ropes. Mr. Andrew Smith's wire ropes have been used in mines, for the rigging of ships, and for other purposes, among which may be mentioned the drawing of the trains in the London and Blackwall railway before the introduction of locomotives on that line. These ropes are formed in various ways according to the uses to which they are to be applied. For standing rigging straight untwisted wires are bound round with cloth or small hempen cordage saturated with a solution of caoutchouc, asphaltum or other preservative against rust. Flat ropes are made of straight wires or wires with a slight twist, interwoven or wrapped with hempen yarn or sewed between canvas. Other ropes are formed after the method of hempen ropes, the wires being twisted into strands, and combined into ropes either hawser-laid or cable-laid. The torsion must not be so hard as in hempen ropes, and the wires must be coated with tin or zinc, or other protective from rust. Mr. Newall recommends the following composition for the coating:—Tar 6 parts, linseed oil 2, tallow 1 part; the whole to be melted together and applied while hot. In Mr. Newall's patent the wires are twisted round a core of wire, hemp cord, spun yarn, or other material to form a strand; and if more than 3 strands are used in a rope they are laid round a similar core. In joining the wires the ends should be twisted together for a few inches or even soldered or

(1) The length, weight, and value of the cordage required by a first-rate ship of war is as follows:—

Total weight, 78½ tons.

Total length, 43 miles, all the cordage, great and small, being supposed to be tied together, and extended in a right line.

Total cost, at the average price of 42*l*. per ton, 3,276*l*.

welded. Wire ropes may be secured at their ends by passing them through the small end of a conical collar, and doubling up or *upsetting* the ends of the wires, which may then be welded into a solid mass, or secured by running melted brass or solder among them. The collars may then be attached to the hook, eye or joint with which it is required to connect the rope, or they may be screwed together so as to unite several lengths of rope.

Copper, brass and other metals are also used for wire ropes, some of which are made of small size for hanging pictures, &c.

The comparative size and weight per fathom for equal strengths of hemp and wire ropes are given in the following table, the results of experiments with Mr. Andrew Smith's wire ropes:—

Hemp rope. Size. Inches.	Hemp rope. Weight per fathom. lbs.	oz.	Wire rope. Size. Inches.	Wire rope. Weight per fathom. lbs.	oz.	Equal to a strain of tons.	cwt.
3	2	4	$1\frac{1}{4}$	1	4	2	10
4	3	15	$1\frac{1}{2}$	1	9	3	10
5	6	0	$1\frac{3}{4}$	1	14	6	15
6	9	0	2	2	2	8	0
7	12	3	$2\frac{1}{4}$	2	9	8	11
8	14	3	$2\frac{1}{2}$	4	1	9	18
9	19	6	3	5	4	15	6
10	25	0	$3\frac{1}{2}$	7	1	24	6
11	30	0	4	11	6	29	5
12	36	8	$4\frac{1}{2}$	15	12	35	4

ROSE-ENGINE. See TURNING.

ROSEMARY, OIL OF, an essential oil prepared chiefly in Spain and the south of France by distilling the leaves and flowers of the *Rosmarinus officinalis.* At first it is nearly transparent and very limpid; but it becomes yellowish and thick by age. It has the strong penetrating odour of the plant, with a camphor-like addition: its taste is burning and it has an acid reaction. The sp. gr. is about 0·91, but it varies with the age and purity of the oil. It mixes freely with alcohol. By evaporation or by shaking it up with potash it deposits a stearoptene or *rosemary-camphor.* The oil of the rosemary of commerce is prepared from oil of turpentine distilled with rosemary; it is also adulterated with spike oil. This artificial preparation does not redden litmus.

Oil of rosemary is chiefly used as a perfume. It enters into the composition of Hungary water, eau de cologne and aromatic vinegar: it is also said to promote the growth of hair and to prevent baldness. Distilled oil of rosemary according to Dumas has a sp. gr. of 0·885 to 0·887, and consists of $C_{80}\,H_{64}+2HO$; that is, a hydrate of a hydrocarbon, isomeric with the distillate of oil of turpentine.

ROSIN. See TURPENTINE.

ROSIN GAS. See GAS.

ROT, DRY. See TIMBER.

ROTTEN-STONE. A variety of TRIPOLI, almost peculiar to England. It occurs abundantly in Derbyshire and South Wales, and is much used for giving polish and lustre to articles in silver, glass, and stone. See GRINDING and POLISHING.

ROUGE. See SAFFLOWER—CARMINE.

RUBBLE-WORK. See MASONRY.

RUBY. See SAPPHIRE.

RUDDER. See SHIP.

RUM, a spirit distilled in the West and East Indies from a fermented mixture of molasses and water, with the skimmings from the sugar boilers and the *dunder*, or lees, or spirit wash of former distillations. The average strength of rum is 53 to 54 per cent. of alcohol, sp. gr. 0·825 at 60°. The flavour of rum is referred to an oily product, probably formed during fermentation, and to which the sudorific property of rum is ascribed. [See SUGAR.]

RUMBLE, or SHAKING MACHINE, a cylindrical vessel like a churn, used for polishing small articles by their mutual attrition. It is usually made to revolve by a winch-handle or pulley; but is sometimes shaken endways by a crank so as to imitate the mode of cleaning nails by shaking them in a sack, whence it derives its second name.

The rumble is used for polishing needles and brass pins with sawdust and bran; steel pens, with sawdust, after the hardening and tempering; bone buttons, with Trent sand; lead shot, with black-lead; for scouring small castings to remove the sand coat; for brightening iron tacks with water before being tinned; for cleaning the rust off cannon balls; for drying small articles in sawdust, such as the blanks for coin, after they have been annealed and pickled with acid; for dissolving gums in spirits of wine, for making lackers and varnishes: such are a few of the uses to which the rumble is applied.

RUSH. The application of the common soft rush (*Juncus effusus*) to the making of rush-lights is explained under CANDLE. The *J. effusus* and the *J. conglomeratus*, or the common rush, are used for plaiting into mats, chair-bottoms, and for making small baskets. The Dutch rush (*Equisetum hyemale*) is used for polishing hard woods, alabaster, marbles, and some other substances, for which it is adapted by the quantity of silica disseminated through its outer surface. The rush is about the size of a writing quill, of a greenish-grey colour, and a rough grooved surface; it is gathered in pieces from 2 to 3 feet long, which are intersected by knots at distances of 4 to 6 inches. It is said to be a native of Scotland: it thrives in the marshy places of mountainous districts. It contains rather more than 13 per cent. of ash, which consists of silica 6·38, carbonate of lime, 5·51, potash salts 0·79, and alumina 0·46.

RUST, a term applied to the red oxide of iron, which forms on the surface of iron by exposure to air and moisture.

RYE, a plant of the family of the Gramineæ, bearing naked seeds on a flat ear furnished with awns like barley. Its straw is valuable for thatching, and also for litter. Rye is extensively cultivated on the Continent, especially in the Netherlands, where it is used for distilling the spirit named *Hollands:* this is flavoured with juniper, or, as the Dutch call it, *genever*, whence the name *geneva* and its contraction *gin.* When rye is malted it makes beer of good quality. According to Einhof rye consists of husks 24·2, flour 65·6, and water 10·2 per cent. The flour contained 61·07 per cent. of starch, 9·48 of gluten,

3 28 of vegetable albumen, 3 28 of uncrystallizable sugar, 11·09 of gum, 6·38 vegetable fibre, and the loss was 5·62. Phosphates of lime and of magnesia were also present.

SABLE. See Fur.

SACCHAROMETER. See Beer, Fig. 111.

SAFETY-LAMP. See Coal, Figs. 576, 577.

SAFETY-VALVE. See Steam.

SAFFLOWER, the dried flowers of *Carthamus tinctorius*, the chemical principles of which are given under Carthamus. It is an annual composite plant, cultivated in India, Egypt, Spain, and the Levant, &c. on account of its dyeing properties. The flowers are the only parts used in dyeing: these yield two sorts of colouring matter; the first yellow, and of little value; the second, a pink of great delicacy and beauty, but not very permanent. The yellow colour of safflower is soluble in water, the pink is resinous in its nature, and is best dissolved by the fixed alkalies. The flowers of the carthamus are gathered, placed in a bag, and trodden under water to get rid of the yellow colour. They are then placed in a trough with soda, in the proportion of 6 lbs. to 120 lbs. of carthamus. After soaking for a time, the contents of the trough are transferred to another, having a perforated bottom, but lined with a finely-woven cloth. This perforated trough is placed over an unperforated empty one, and water is poured through the upper one. This carries with it a large amount of the colouring matter released by the alkali. When the lower trough is full the bath is placed over another trough. A little more alkali is added and fresh water, until the latter runs through without carrying any more colouring matter. Lemon juice is added to the dye stuff in the troughs, and raises the colour to a bright cherry-red. Silk, in hanks, is then immersed and turned round skein-sticks in the bath as long as it will take up any colour. It is then dried, and if the colour be not deep enough, it is passed through another bath of similar strength. A final brightening is given by turning the silk round the skein-sticks 7 or 8 times in warm water with lemon-juice, in the proportion of half a pint to each pailful of water.

This colour will not bear the action of soap, nor will it long withstand exposure to the sun and air; it is chiefly employed on silk for imitating the fine dye of the French called *ponceau*. For *ponceau*, or flame-colour, the silk is first boiled, and then receives a slight foundation of annotto; but it must not be alumed.

Safflower is a costly dye: it is chosen in flakes of a bright pink colour; that in powder, dark-coloured, or oily, is of inferior quality. The beauty of the colour, in its purest form, has caused it to be employed in the manufacture of *rouge*. The preparation of rouge from cochineal is described under Carmine. The delicate and beautiful rouge, known as *rouge végétale*, is nothing more than the colour of safflower which has been extracted by means of crystallized soda, precipitated by citric acid, then slowly dried, and ground up with the purest talc. Dr. Ure's account of the process of rouge-making from safflower is as follows: "The flowers, after being washed with pure water till it comes off colourless, are dried, pulverized, and digested with a weak solution of crystals of soda, which assumes thereby a yellow colour. Into this liquor a quantity of finely carded white cotton wool is plunged, and then so much lemon-juice or pure vinegar is added as to supersaturate the soda. The colouring matter is disengaged, and falls down in an impalpable powder upon the cotton filaments. The cotton, after being washed in cold water, to remove some yellow colouring particles, is to be treated with a fresh solution of carbonate of soda, which takes up the red colouring matter in a state of purity. Before precipitating this pigment a second time by the acid of lemons, some soft powdered talc should be laid in the bottom of the vessel for the purpose of absorbing the fine rouge, in proportion as it is separated from the carbonate of soda, which now holds it dissolved. The coloured mixture must be finally triturated with a few drops of olive-oil in order to make it smooth and marrowy. Upon the fineness of the talc, and the proportion of the safflower precipitate which it contains, depends the beauty and value of the cosmetic. The rouge of the above second precipitation is received sometimes upon bits of fine-twisted woollen stuff, called *crepons*, which ladies rub upon their cheeks."

SAFFRON consists of the stigmata of the flowers of a perennial bulbous plant (*Crocus sativus*), once extensively cultivated at Saffron Walden in Essex, and still fostered in some parts of Cambridgeshire. From this small portion of the flower is obtained a rich yellow-red colour, which, when dried and pure, is of a scarlet hue. Saffron is imported from Sicily, France, and Spain, but the foreign product is not so much esteemed as the English. The use of saffron is, however, diminishing. It is employed as a seasoning in cookery: also to colour confectionary, liqueurs, varnishes, and sometimes cheese and butter. It is used to a small extent by painters and dyers. It was formerly much used in medicine as a carminative, antispasmodic and emmenagogue, and it is still occasionally employed to promote the eruption of certain diseases of the skin. On the same principle it is given to birds to assist their moulting. Dr. Lindley describes the colouring ingredient of this plant as "a peculiar principle to which the name of Polychroite has been given; it possesses the properties of being totally destroyed by the action of the solar rays, of colouring in small quantity a large body of water, and of forming blue or green tints when treated with sulphuric and nitric acid, or with sulphate of iron. In moderate doses, this substance stimulates the stomach, and in large quantities, excites the vascular system. Moreover it seems to have a specific influence on the cerebro-spinal system, as it affects, it is said, the mental faculties, a result which De Candolle considers analogous to that produced by the petals of certain odorous flowers." Saffron is known in commerce as a kind of fibrous cake. This should be moderately moist, close, tough, and compact, the smell sweet and penetrating, the taste warm, pungent, and somewhat bitter.

SAGO. See STARCH.

SAIL, a coarse linen or canvas sheet attached to the masts and yards of ships, the blades of windmills, &c., for the purpose of intercepting the wind, and occasioning their motion. See SHIP—WINDMILL.

SAL AMMONIAC, a compound of ammonia and hydrochloric acid, NH_3,HCl, now called *hydrochlorate of ammonia*, although the older term, *muriate of ammonia*, is also used. The substance from which this salt was first obtained, was the soot of camel's dung; and it was formerly produced therefrom by sublimation in large quantities, in Egypt, near the temple of Jupiter Ammon, whence the name *sal ammoniac*. It is now manufactured largely in Europe, by combining hydrochloric acid either directly or indirectly with ammonia obtained from the decomposition of animal matter. In France, bones and other animal matters are distilled in large iron retorts, for the manufacture both of animal charcoal and of sal ammoniac. Coal soot was formerly used in Great Britain as a source of this salt; but since the establishment of gas works, it has been chiefly derived from the liquor obtained during the preparation of coal gas. [See GAS.] The impure carbonate of ammonia contained in this liquor is either at once saturated with hydrochloric acid, or it is first converted into sulphate of ammonia, and afterwards by decomposing it with common salt into hydrochlorate; the products being sulphate of soda and hydrochlorate of ammonia: the latter is separated by crystallization and sublimation. This salt, as obtained by sublimation, is amorphous, somewhat elastic, translucent, and colourless; and of the sp. gr. 1·45 to 1·50, but when obtained by crystallization, its form is octohedral and cubic. Its taste is sharp and saline: it has no smell; it dissolves readily in water; it does not change in dry air, and volatilizes by heat, without undergoing decomposition. It is decomposed by lime, and the fixed alkalies, with the evolution of ammoniacal gas: sulphuric acid expels hydrochloric acid gas from it.

Sal ammoniac is used in the arts for a variety of purposes; as in pharmacy for making ammoniacal preparations: in tinning, to prevent the oxidation of the surface of the copper: when dissolved in nitric acid it forms the *aqua regia* of commerce, used for dissolving gold instead of nitrohydrochloric acid. It is also used in small quantities in steam boilers, to prevent the formation of calcareous deposits.

SALEP. This nutritive mucilaginous substance is obtained from the subterraneous succulent roots of several species of orchis, especially *Orchis mascula*, thus forming one of the few exceptions to the general rule, that orchidaceous plants, which charm and astonish by their elegant, varied, or grotesque forms are without known utility to man. Salep is a powder prepared from their dried roots; in some cases, as in that imported from India, it is in hard clear pellucid inodorous pieces. There is not much demand for this substance, although it is considered a bland and nutritious article of diet, taken with milk, in the same way as arrowroot. The orchis which yields it thrives well in England, but is not cultivated to any extent.

SALICINE, a peculiar, crystallizable, bitter principle, obtained from the leaves and young bark of the poplar, willow, aspen, &c. It forms small white silky needles, and in some respects, resembles the vegeto-alkalis, cinchona, and quina, having febrifuge properties; but it differs from them in containing no nitrogen, and not forming salts with acids. Its formula is said to be $C_{26}H_{18}O_{14}$.

SAL PRUNELLA, a term applied to nitrate of potash, fused and cast into balls resembling prunes or plums, and sometimes coloured to resemble them.

SAL VOLATILE. See AMMONIA.

SALT, EPSOM. See MAGNESIA, *sulphate of.*

SALT, MICROCOSMIC, the triple phosphate of soda and ammonia. See MICROCOSMIC SALT.

SALT OF AMBER is succinic acid. See AMBER.

SALT OF LEMONS. This term can only be correctly applied to CITRIC ACID; but the oxalate of potash used for removing iron moulds is called by this name. See OXALIC ACID.

SALT OF SATURN is the acetate of lead. See LEAD.

SALT OF SODA is carbonate of soda. See SODIUM.

SALT OF SORREL is binoxalate of potash. See OXALIC ACID.

SALT OF TARTAR is carbonate of potash, so called from its being obtained by burning purified *tartar*, (bitartrate of potash,) lixiviating the residue, and evaporating to dryness.

SALT OF TIN, the protochloride of tin.

SALT OF VITRIOL, a term applied to white vitriol, or sulphate of zinc.

SALT PERLATE is phosphate of soda.

SALTPETRE is nitrate of potash. See POTASSIUM.

SALT, SEA or CULINARY. See SODIUM.

SALT SEDATIVE is boracic acid.

SALTS. See METAL.

SAND. This name is popularly applied to any comminuted minerals, but properly belongs to granular quartz, silica, or flint, the chief ingredient in the sands of the deserts, sea-shores, river banks and soil. Sand is produced by the disintegration of rocks, and its colour, which is generally imparted by oxide of iron, may be red, white, grey, or black. The pure colourless sands are much in request for the manufacture of glass. [See GLASS.] Sand is also used for making mortars, [see MORTARS and CEMENTS,] for filters, [see FILTRATION,] and in the operation of founding, [see CASTING and FOUNDING.] Sand is also used in sawing and smoothing building stones and marbles, [see MARBLE,] and in many other grinding and polishing operations. River and pit sand are usually sharper than sea sand, for this has been rounded by attrition. The washed scrapings of roads which have been repaired with flints furnish the sand used by stone masons. *Grindstone dust* is a form of sand useful for some purposes; it cuts deeper than *Flanders brick*, which is another form in which sand is used. Grindstone dust is formed during the turning of the grindstone into form, or it may be made

by crushing the grit or grindstone with a hammer, or with a pestle and mortar. *Trent sand* is a fine and sharp sand, collected from the banks of the Trent, which flows into the Humber. This sand is much used at Sheffield and other places for polishing; it is an economical substitute for emery and other polishing powders, and is much used for Britannia metal goods. The Sheffield cutlers make this sand into balls, which they put in the fire for a few hours; they are then crushed and passed through a fine hair sieve; this burnt sand is thought to cut more readily than the unburnt. Blue grit stone crushed and pulverised is used for common cutlers' work. *Flander's* or *Bath bricks* are made at Bridgewater, of a clay containing a large proportion of fine sand; they are much used for domestic purposes, and also in the state of powder for polishing bone, ivory, and soft metals; and in dressing cutler's dry buff wheels. *Sand-paper* is made of common house sand of one degree of coarseness; it is less useful than *glass-paper* when applied to wood, but its effect on metals is intermediate between that of glass-paper and emery-paper. Sand-paper is prepared in the same manner as glass-paper. As the latter useful article was not noticed under its proper heading, it may find an appropriate place here. In making *glass-paper*, fragments of broken wine bottles are well washed to remove the dirt; the glass is crushed under an edge runner, and then sifted into about six sizes. The paper is brushed over with glue, the glass dusted over it from a sieve. Thin cotton cloth is also used instead of paper; and Venetian red is sometimes mixed with the glue for the sake of the colour. Calcined flint has also been used instead of the glass. [See EMERY—GRINDING and POLISHING.]

The use of sand as a measure of time is noticed under HOROLOGY. It is stated in that article that the flow of sand, unlike that of water, is perfectly equable. In the *sand* or *hour-glass*, for example, there is an equable flow from the upper into the lower bulb whatever quantity of sand be above the aperture; and the larger quantity of sand does not, as in the case of water, act by its weight or pressure in accelerating the flow. This may be proved by a few experiments.[1] A glass tube of any length and diameter is to have its lower extremity closed with a piece of writing paper, the edges of which may be secured with string to the outside of the tube. A small hole about $\frac{1}{8}$th inch in diameter is to be made in the centre of the paper bottom, and the finger being placed on this hole, the tube is to be filled up with fine dry sand. If the tube be suspended and portions of the sand allowed to flow out, each portion sufficient to fill a small cup, the time required to fill this cup will always be the same. Or if the tube be graduated on the outside the time occupied by the sand falling from one division to another will be found to be the same in any part of the tube. This would evidently not be the case with water. When the sand is flowing, any pressure exerted on the upper surface of the sand will have no effect in accelerating the flow. If the bottom of the tube be closed with a thin film of silver paper, and a solid cylindrical plug be rammed in at the top, no force that we can exert will displace the paper at the bottom.

To explain these remarkable phenomena it must first be noticed that when sand is allowed to fall quietly upon a plain surface it forms a conical heap, the sides of which form with the base, an angle of about 30°. Now when the sand is poured into the tube it forms therein a succession of conical heaps which support each other and rest against the sides of the tube, the last heap only being supported by the paper bottom. Now when any pressure is applied to the top surface of the sand it is not transmitted, as in the case of water; it acts to a very small depth laterally, but has no perpendicular action. Hence we see that the reason why the sand flows so equably in the sand-glass, &c., is that the lowest heap is not influenced by the pressure of the heaps above. This shows us also how it is that sand is so excellent a tamping material for filling up the holes made for the gunpowder in blasting: [See MINE—MINING, Fig. 1465]. The pressure not being transmitted by the sand the force of the gunpowder is not wasted by discharging smoke and dust into the air, but acts with full effect upon the rock which is to be severed.

SANDSTONE, an aggregation of sand by a sort of semifusion as in quartz rock, and in common gritstone, adjoining trap dykes or great faults. [See COAL, Figs. 571, 572. See also GRINDSTONE—GRIT.] In many of the white sandstones the grains merely cohere together. In the sandstones of coal tracks the finer particles of carbonate of lime, clay, oxide of iron, &c., are interposed between the grains: in other cases, as in the Hastings sandstones, an infiltration of carbonate of lime has taken place. Some sandstones are in laminæ, plane, waved, or slightly concentric: these admit of being readily split. The freestones [see FREESTONE] are not distinctly laminated, the grains being so arranged as to present equal resistance in every direction. They work *freely* under the stone saw (Fig. 1393) and the ordinary picks and chisels. They can also be turned into balustrades, pedestals and vases.

SANDAL WOOD, a fragrant wood much used among the Chinese in cabinet work, and in the manufacture of fans and other ornamental works. It is the produce of a small tree (*Santalum album*) growing in India and Ceylon, which gives its title to the natural order of plants called *Santalaceæ* or Sandalworts. The sandal-wood of the Sandwich islands is from two other species of the same family, *S. Freycinetianum* and *S. paniculatum*. In the native medical practice of India, Sandal-wood furnishes a sedative cooling medicine; it is also largely employed as a perfume in the funeral ceremonies of the Hindoos. By the Chinese it is ground into powder and used as a cosmetic. The bark affords a beautiful red dye, but so fugitive as to be useless. The tree grows

(1) These experiments, and further particulars respecting the hour-glass, are given in the Editor's "Student's Manual of Natural Philosophy." 1838.

freely among the mountains of Malabar, near the sea-coast, whence Calcutta obtains her supply of sandal wood, and in Timor and the Feejee islands, from which China derives her chief supply.

The tree is cut down when about 9 inches diameter at the root: it is then cleared of its bark, and cut into logs, which are buried for six weeks or two months in order that the white ants may clear off the outer wood; this they do most effectually, without touching the heart of the tree, which is the only valuable part. Sandal-wood should be of a fine deep yellow brown, and highly perfumed. The average importation of this wood into Calcutta is 200 tons per annum. The Chinese imported an amount of sandal-wood in 1838 worth about one hundred and fifty-thousand dollars, but this is said to be doubled in some years. The supply to Europe is very small, and chiefly derived from that which has been brought over by individuals without a view to commerce.

SANDARACH, a resinous substance, said by some writers to exude in hot climates from the bark of the common juniper-tree (*Juniperis communis*). Other state it to be produced by another tree of the pine tribe called *Thuja articulata,* but according to Brongniart and Schousboe, it is the tears of *Callitris quadrivalvis,* also a coniferous tree. Dr. Lindley says, "I have seen a plank two feet wide of this sandarach tree, which is called the arar tree in Barbary. The wood is considered by the Turks indestructible, and they use it for the ceilings and floors of their mosques." The resin is received in the form of loose granules or tears, whitish yellow, brittle, and having a faint resinous smell, and acrid taste. It is used, dissolved in spirits, as a varnish; it is also employed as incense, and as a pounce-powder.

SAPPHIRE, a gem of a blue colour consisting of pure alumina; it occurs in six-sided prisms often with uneven surfaces. It also occurs granular. When the surface is polished, a star of six rays corresponding with the hexagonal form, is in some specimens seen within the crystal. The sapphire ranks next to the diamond in hardness. When it occurs in *dull dingy-coloured* crystals and masses, the term *corundum* is applied to it, and the granular variety of bluish grey and blackish is called *emery*. [See Emery.] When the sapphire occurs of other *bright* tints other names are applied to it, a list of which is given in the tables of hardness under Lapidary work. The application of the sapphire to the Jewelling of watches is given under that head.

Some of the varieties of the sapphire rank next to the diamond in value. Indeed the oriental ruby, of fine colour and free from flaws, is more valuable than a diamond of equal weight. In Mr. Hope's collection is a blue sapphire which cost 3,000*l*.

SARD, SARDONYX. See Agate.

SARSAPARILLA. The roots of several species of climbing evergreen plants found mostly in warm and tropical climates, and belonging to the genus *Smilax*. The name sarsaparilla is derived from the Spanish word *zarza*, a bramble, and *parilla*, a vine. The original species, *Smilax officinalis,* is a native of South America, but there are several other kinds which also contribute to furnish the roots known in commerce as genuine sarsaparilla, and whose properties are scarcely inferior to it. Of the South American sarsaparilla some reaches us by way of Jamaica and has the name of that island, while a large quantity is shipped at the Brazils and is called Lisbon sarsaparilla. Varieties of this root are also found in the South of Europe and in India. East Indian sarsaparilla, long thought to be the root of *smilax aspera,* but now said to belong to *Hemidesmus Indicus,* is abundant and cheap, and as it appears to partake largely of the qualities of the true sarsaparilla, there is no doubt of its being extensively employed as a substitute.

Sarsaparilla is valued as a restorative to debilitated constitutions. According to Brande there is as yet no good analysis of this root, and the extraordinary medical qualities which it is said to possess are to be attributed rather to its general composition than to any distinct principle.

SATIN. See Weaving.

SATIN-SPAR is a variety of fibrous gypsum. See Gypsum.

SATURATION. See Solution.

SAW, an important cutting instrument used in the preparatory processes of reducing wood, ivory, and other substances, to shape. It is not much used for the metals: the desired forms being given to them by casting, hammering, rolling, filing, &c. A good saw ought to be of uniform thickness in the blade, and so elastic, that when bent into a bow it will spring back again to a straight line on removing the pressure. These qualities are best ensured by cutting the blade out of a sheet of steel formed by rolling an ingot of the cast metal. If intended for a *mill* or *pit-saw,* a large sheet is clipped with shears to the proper shape: for smaller saws, the sheet is cut up into the required sizes. The shears used for the purpose are arranged with due regard to strength and stability, the upper blade being raised and depressed with a long lever, as shown in Fig. 1915. The edges of the pieces are

Fig. 1915. CUTTING OUT THE BLADES.

ground true by holding them against a large grindstone, as shown in Fig. 1916. The teeth are cut out by a punch at a fly-press [see Punching, Fig. 1802],

the distance between the teeth being accurately regulated by an upright steel gage by the side of the cutting-punch, and shifting the blade one tooth for-

Fig. 1916. GRINDING THE BLADES.

ward after the cutting of each tooth, the gage falling into the space between two teeth. In cutting the teeth of long saws, which are too heavy and pliable to be held in the hand, the ends are supported by swing-rests suspended from the ceiling by cords. The forms of teeth are very various, and will be noticed more particularly hereafter. Fine saw-teeth may be indented with a double chisel, one edge of which is inserted each time in the notch previously made, and the other edge makes the following indentation: the intervals, thus being truly equidistant, the teeth are completed with a file. Piercing or inlaying saws are made from pieces of watch-spring, straightened by rubbing them the reverse way of their curvature through a greasy rag: these saws are about $\frac{1}{30}$th inch wide, $\frac{1}{100}$th inch thick, and have about 20 points to the inch for wood, 30 for ivory, 40 for ebony and pearl, and 60 for metals. The saw is made by being distended in a frame, laid in a shallow groove in a plate of brass imbedded in wood, and the teeth are set out with a file by a process of *stepping*, during which the file rests alternately on the saw blade and on the edge of the block. But to return to the manufacture of the larger and more common varieties of saws. After the teeth are cut the blade is put into a vice, and the wire edges left by the punch are filed down, and the teeth are *sharpened*. The next process is *hardening*. Saws require a milder degree of hardness than is obtained by raising the metal to a red heat and quenching in water. The proper degree of hardness is obtained by quenching in a bath of oil in which various ingredients, such as tallow, suet, bees'-wax, resin, pitch, &c., have been melted. The saws are heated in long furnaces, and then immersed horizontally and edgeways into a long trough containing the composition. It is usual to employ two troughs, the second being brought into service when the first gets too hot. When the saws are removed from the trough they are very hard and brittle, and require *tempering;* for which purpose a portion of the composition is wiped off with a piece of leather, and each saw is heated over a coke fire until the grease inflames, an operation which is called *blazing off*. If the saws are to be rather hard, only a small portion of the grease is blazed off; but a larger portion for a mild temper.[1] The composition loses its property of hardening steel after a few weeks' constant use. The trough should be well cleaned out before a new mixture is put into it. Mr. Gill recommends for the composition 20 gallons of spermaceti oil, 20 lbs. of beef suet (rendered), 1 gallon of neats'-foot oil, 1 lb. of pitch, 3 lbs. of black resin. The pitch and the resin are to be melted together before being added to the other ingredients. The whole is heated in an iron vessel with a closely-fitting cover, until the moisture is nearly driven off, and the composition inflames on presenting a burning body to its surface. The flame must however be instantly extinguished by putting on the cover. In tempering large saws they are stretched in an iron frame moving on wheels, so that they can be returned to the furnace and moved to and fro over the fire until the grease begins to blaze off. They are then removed from the furnace and allowed to cool, and occasionally stretched tighter in the frame to prevent warping. *Back-saws*, or those which are afterwards furnished with a brass or iron back to keep them straight, are made in lengths of several feet, and at a subsequent stage are cut up into 3 or 4 saws. These lengths are hardened and tempered in the same manner as large saws; but saws of medium size are tempered by holding them one at a time with a pair of tongs, and moving them over a fire for the blazing-off.

The next operation is *planishing* or *smithing*, for which purpose the saw is rested on an anvil of polished steel, and hammered over every part of its surface, more in some parts than others, according to the judgment of the workman, the object being to impart to the metal an equal density and elasticity throughout.[2] The internal texture having been thus equalized, the blade is *ground* at the *wheel* or grindstone, Fig. 1916. The stones are from 5 to 7 feet in diameter, and 10 or 12 inches across the face: the grinding is *wet*, and the saw is applied to the stone chiefly crossways so as to reduce the thickness of the metal from the teeth towards the back: the blade is placed against a board, upon which the grinder presses and moves it about during the grinding. The larger saws are suspended at both ends from the top of the mill.

The flatness and elasticity of the saw have been impaired by the grinding: it is therefore planished a second time to restore its flatness: it also partly receives its elasticity in this process and partly by the next, which consists in holding it over a coke fire until a faint straw colour appears. It is now passed lightly over the grindstone in the direction of its length in order to remove the marks of the hammer, and is next smoothed upon a hard smooth stone. It

(1) In tempering clock-springs the whole of the grease is burnt off.

(2) On this subject we may refer to a very instructive section in the 18th chapter of Holtzapffel's "Mechanical Manipulation," entitled "The Principles and Practice of Flattening thin Plates of Metal with the Hammer."

is polished upon a buff or glazer, and again planished or *blocked*, as it is called—the anvil being a block of hard wood. The saw is next *cleaned off* by women, with coarse emery, rubbed on with cork, which produces an even, white, level tint.

The last process is the *setting* of the teeth: that is, every alternate tooth is to be bent a little on one side, and the intermediate teeth, to an equal extent, on the other side, so that each tooth may form an acute angle with the surface of the saw. The object of this setting is to prevent the teeth from becoming choked up with sawdust, and also to give sufficient breadth for the working of the saw, the *kerf* or cut made by it being thus wider than the thickness of the blade. In setting a saw, the saw-maker fixes in the tail-vice a small anvil or stake, Fig. 1917, with a rounded edge, and the teeth of the saw being laid upon the rounded edge of the stake, he strikes every alter-

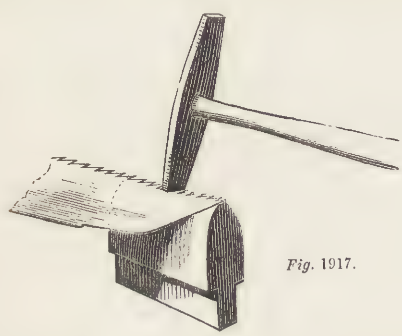


Fig. 1917.

nate tooth with a small hammer so as to bend it round the curve: the face of the hammer is at right angles to the handle, and sufficiently narrow to strike only one tooth at a time. Half the teeth having been bent in this way the saw is turned over, and the alternate teeth are treated in a similar manner. The amount of set is determined for the most part by the curve of the stake. The saw-maker performs the operation with great precision and rapidity; but for amateurs, who have not acquired his skill, *saw-set pliers* are provided, by which they can do the work much more slowly, but with much less risk of breaking off the teeth. The teeth are next filed up sharp; for which purpose the saw is placed in a vice, between slips of wood or clamps of sheet-lead, in order to prevent that unpleasant schreeching noise which accompanies the action of the file when the saw is not held securely. The saw is once more held over the fire for the purpose of tempering it, and the thin film of oxide is washed off with very dilute hydrochloric acid. The saw is now ready for *handling*. The handles are cut out of a plank of beech by means of a hand-saw; then worked up with files and rasps, and polished with a whale-fin and a bone burnisher. The back plate, when required, is also fitted; it is a piece of iron folded together so as to form a groove, which clasps the back of the saw like a spring.

Saws may be divided into two great classes, the *rectilinear* and the *circular;* the former are generally used by hand; the latter are always combined with machinery. In the straight saw the thickness of the blade is reduced by grinding from the teeth towards the back: in the circular saw, the blade is usually of the same thickness throughout: in the veneer saw, however, it is thinned away at the edge.

The inclination of the face of the tooth is called the *pitch*. In wheels and screws the pitch is the interval from tooth to tooth: the saw-maker defines this interval by the number of *points* to the inch, and these may be 2, 3, 4, 5, to 20; but where the intervals between the points of the teeth are very wide, as from ½ to 1¼ inch, they are said to be *half* or *one and a quarter inch space*. Some of the circular saws are as coarse as 2 to 3 inches.

With respect to the forms of the teeth, Fig. 1919 *b*, may be taken as the most simple, capable as they are of being produced by angular notches filed with two of the sides of an equilateral triangular file, so that the points assume the same angle as the spaces, viz. 60°.[1] This angle of 60° is variously placed: the teeth, in *b*, are said to have an *upright* pitch, although, in fact, there is no pitch; while the teeth in *d* are said to be *flat*, or to have a considerable pitch. Between these two extremes the inclination or pitch is very various.

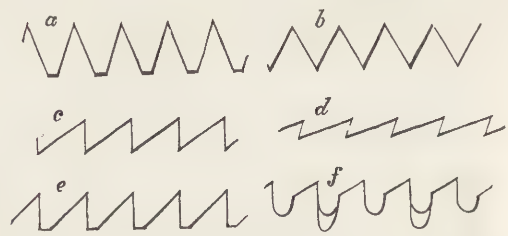


Fig. 1918.

In general, the angles of the points of the teeth are more acute the softer the material to be sawn.

Fig. 1918 *a*, is a common form of tooth, called the *peg-tooth*, or the *fleam-tooth*. This, as well as *b*, is used for *cross-cutting* saws, or those which cut across the fibre of the wood: the saw has a handle at each end, and is worked by two or more men, as in cutting down trees and dividing them when they have been felled. Similar saws are used for cutting the soft building stones when first got out of the quarry. The *gullet-tooth*, *f*, is also used for cutting timber across. *c* is the tooth in most general use; it is known as the *ordinary-pitch*, or *hand-saw-tooth*, and is much used by cabinet-makers and joiners; also for circular saws for fine work, such as veneer-saws, and for many cross-cutting circular saws, and for saws used for metal. In some cases the acute angular

(1) The angles of the faces and of the tops of the teeth are measured from the line running through the points of the teeth or the edge of the saw. The angle of the point itself is found by subtracting the angle of the back from that of the face of the tooth or the less from the greater of the two numbers. In the illustrations given the angles and spaces are as follows:—

		ANGLES. Face.		ANGLES. Back.		SPACES.
Fig. 1918,	*a*	110°	......	70°	......	⅝ to 1¼
—	*b*	120	......	60	......	⅝ to 1¼
—	*c*	90	......	30	......	⅜ to 1
—	*d*	75	......	15	......	¼ to 2½
—	*e*	90	......	50	......	¾ to 4
—	*f*	90	......	30	......	⅜ to 3½

notch is not continued to an internal angle, as in *e*, a form adopted in some mill-saws, both of ordinary or perpendicular pitch, as well as for those of greater pitch. This kind of tooth being more acute than 60°, does not admit of being sharpened with the 3-square or equilateral file, but with a thin flat file, with square or round edges, called the *mill-saw file*. Angular mill-saw teeth are more readily sharpened than the *gullet*-teeth, *f*, so named from the large hollow or gullet cut away in front of each tooth in continuation of the face: they are also called *briar-teeth*. The gullet allows the tooth to be sharpened with a round or half-round file, by which the face of the tooth becomes concave when seen edgeways, and acquires a thin and nearly knife-like edge. The additional curvilinear space leaves more room for the sawdust, and is less disposed to choke than the angular notch. The gullet is sharpened with a round or half-round file. In some cases each alternate tooth is cut out, and the saw is then called *skip-tooth*.

Rectilinear saws admit of being arranged into three groups. 1. *taper*-saws, which if long have a handle at each end as in the *pit saw* and the *crosscut*-saw; but if short, or not over 30 inches in length, there is only one handle, and that is placed at the wide end as in the common *hand-saw*, the *rip-saw, half-rip, broken-space, panel-saw* and *fine-panel*. Of these saws the rip-saw has the coarsest teeth and of slight pitch; the half-rip is a little finer, and both are used in carpentry for *ripping* or cutting fir-timber rapidly with the grain. The hand and fine-hand saws are finer in the teeth, which are of ordinary pitch, and are used for cutting mahogany and other hard woods with the grain. The panel and fine panel saws are still finer: their use in cutting out *panels* for oak and other wainscotting has given them their name.

The narrow taper saws used for cutting curves and sweeps belong to this group. Such are the *table saw*, and the *compass* or *lock-saw*, and the *key-hole* or *fret-saw*. Mr. Holtzapffel remarks that, "it would be desirable, if in the narrow taper saws with only one handle, we more frequently copied the Indian, who prefers to reverse the position of the teeth so that the blade may cut when *pulled* towards him, instead of in the *thrust*: this employs the instrument in its strongest instead of its weakest direction, and avoids the chance of injury. The inversion of the teeth, which in India is almost universal, is with us nearly limited to some few of the key-hole and pruning saws." [1]

The *pruning-saw* has the hand-saw tooth of slight pitch, and also double teeth when living timber is to be cut. The saw is sometimes mounted at the end of a light pole 4 to 6 feet long, so that the edge of the blade may form an angle of about 150° with the handle. It can then be used for branches 8 or 10 feet from the ground. Pruning saws are also mounted in buck-horn handles like carving knives, and are also made as clasp or pocket knifes.

II. The second group consists of *parallel saws with backs*, or those which are stiffened by a rib placed on the back of the saw and parallel with the teeth. The blade is thin and the back is a piece of stout sheet iron or brass folded together first at an angle between top and bottom tools, and then closed with a hammer upon a parallel plate thicker than the saw. The inside of the groove is filed smooth, and the two edges are then grasped in a tail vice and the ridge is hammered to make the edges spring together. The back is held upon the blade by the elasticity thus imparted: the blade only extends about half way down the groove. Back saws are used for accurate work: the *tenon saw* and the *dovetail saw* express by their names the work for which they are used. The *comb-cutter's double saw* is described under COMB.

III. Saws in this group are furnished with an external frame for straining the saw blade in the direction of its length, so as to keep it straight and prevent buckling. The blades are made very thin, and occasion but little labour and waste, and may be used like the Indian saws by *pulling* the blades. In the sawframes "there is a central rod or stretcher to which are mortised two end pieces that have a slight power of rotation on the stretcher; the end pieces are at the one extremity variously adapted to receive the saw, and at the other they have two hollows for a coil of string in the midst of which is inserted a short lever. On turning round this lever the coil of string becomes twisted and shortened: it therefore draws together those ends of the cross pieces to which it is attached, whilst the opposite ends from separating, strain the saw in a manner the most simple, yet effective. The tension of the blade is retained by allowing the lever to rest in contact with the stretcher, as represented Fig. 1920, but when the saw is not in

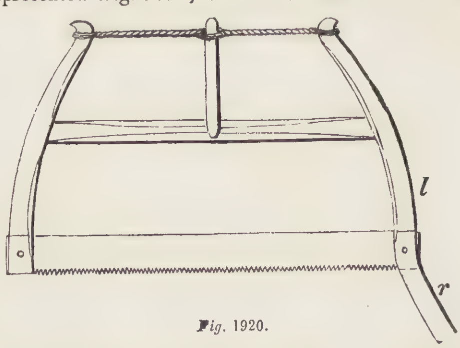


Fig. 1920.

use, the string is uncoiled one turn to relieve the tension of the blade and frame, one or other of which may be broken by an excessive twist of the string." This description, from Mr. Holtzapffel's work, may be illustrated by the *wood-cutter's saw*, Fig. 1920, in which "the end pieces are much curved, and one of them extends beyond the blade which is embedded in

(1) In Holtzapffel's "Mechanical Manipulation" the 27th chapter is devoted to the subject of "saws." It occupies 134 pages and is illustrated by 164 wood engravings. The subject is admirably treated and well worthy the attention of the mechanical reader. Those who have the opportunity of consulting it will also be gratified with Mons. Emy's "Traité de l'Art de la Charpenterie," 2 vols. 8vo., Paris 1837, together with an Atlas of 135 large plates in which are shown the various forms of tools, and the modes of workmanship, essentially different from our own, which are in common use on the continent.

two saw-kerfs and held by a wire at each end: the blade is therefore always parallel with the frame of the saw which is mostly used vertically. The end piece alone is grasped at *r* and *l* by the right and left hands respectively; the wood is laid in an × form sawing horse and is sometimes held by a chain and lever, or less frequently in a strong pair of screw-chops."

The *ivory saw*, the *smith's frame-saw*, and the *side-frame-saw* are small saws in iron frames, and tension is given to the blade by a screw and nut. *Piercing* and *entering*-saws are also fine and keen: the *buhl-cutter's-saw* belongs to this class. [See Buhl-work, Fig. 381.]

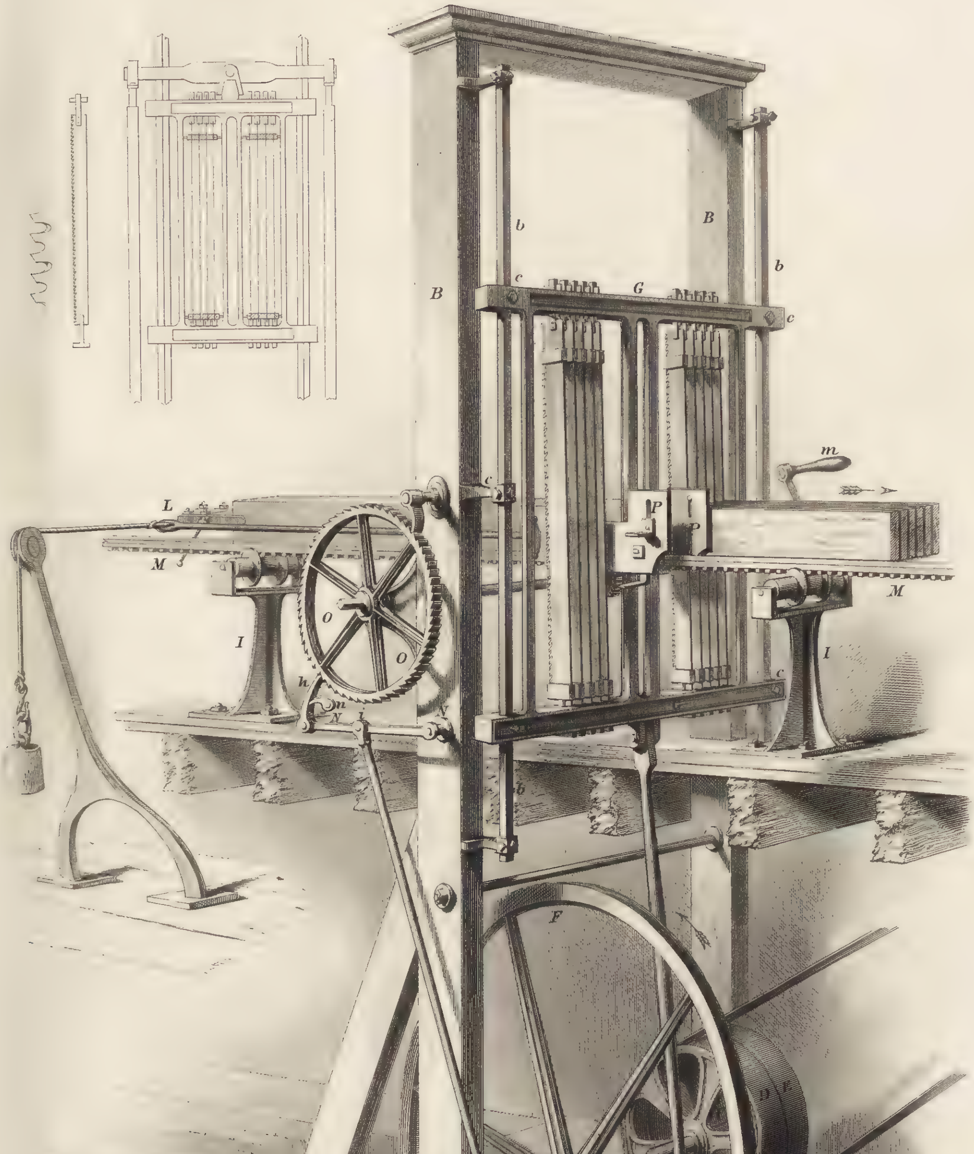
Saw-mills. The operation of sawing by hand is simple but very laborious, and men must at an early period have sought for some means of setting machinery to work for the purpose. According to Beckmann[1] saw-mills driven by water power, were erected so early as the fourth century in Germany on the small river Roer or Ruer. Saw mills do not appear to have been common until about the fourteenth and fifteenth centuries. After noticing their erection in several parts of Europe the learned writer says :—"In England saw-mills had at first the same fate that printing had in Turkey, the ribbon-loom in the dominions of the church, and the crane at Strasburgh. When attempts were made to introduce them they were violently opposed, because it was apprehended that the sawyers would be deprived by them of their means of getting a subsistence. For this reason it was found necessary to abandon a saw-mill erected by a Dutchman near London in 1663; and in the year 1700, when one Houghton laid before the nation the advantages of such a mill, he expressed his apprehension that it might excite the rage of the populace. What he dreaded was actually the case in 1767 or 1768, when an opulent timber merchant, by the desire and approbation of the Society of Arts, caused a saw-mill, driven by wind, to be erected at Limehouse under the direction of James Stansfield, who had learned in Holland and Norway the art of constructing and managing machines of that kind. A mob assembled and pulled the mill to pieces; but the damage was made good by the nation, and some of the rioters were punished. A new mill was afterwards erected, which was suffered to work without molestation, and which gave occasion to the erection of others. It appears, however, that this was not the only mill of the kind then in Britain, for one driven also by wind had been built at Leith in Scotland some years before."

The common saw-mill for cutting timber into planks consists of a square wooden frame in which a number of saws are stretched, which frame, by the motion of a crank, rises and falls in another wooden frame secured to the foundation of the mill. The timber to be cut is placed upon a horizontal bed or carriage, sliding upon the floor of the mill, and sufficiently narrow to pass through the inside of the vertical or moving saw-frame, and thus it carries the tree through and subjects it to the action of the saw. The carriage is provided with a rack, which is engaged by the teeth of a pinion, and by this means the carriage is advanced by turning the pinion by a large ratchet-wheel with a click moved by levers connected with the saw-frame, so arranged that when the saw-frame rises the click slips over a certain number of teeth in the ratchet-wheel, and when it descends to make the cut, the click turns the ratchet-wheel round, and sends the wood forward just as much as the saw cuts during its descent. The trees are dragged up an inclined plane through a door at one end of the mill, and being placed upon the carriage, they pass through, and are divided by the saw into 2 or more pieces, which are carried forward and passed out at a door on the opposite side of the mill.

A saw-mill constructed by Mr. Hague, of Ratcliff, is represented in the steel engraving. A A are timbers built in the foundation of the mill, to which the cast-iron framework B B is bolted by strong bolts and nuts *a a*. C C is a horizontal shaft with a bearing at each end in the sides of the framework. To it are attached the fast and loose pulley D E, over which the working strap is passed; F F is a fly-wheel; G G is the frame in which the saws are fixed: it is guided in its vertical motion by moving on square bars *b b* attached to a projected part of the cast-iron uprights or framing. This method of guiding the saw-frame is attended with very little friction, and any looseness from the wear of the parts may be corrected by screwing up the nuts *c c*. Friction rollers are sometimes employed for diminishing the friction between the saw frame and the channel in which it moves. The saws are fixed and stretched in the frames by wedges, which are driven above through mortices in the upper part or bar of the saw. In this way a number of saws may be fixed on the frame, and to keep the saws at proper distances apart, and to prevent their tendency to twist in the plane of their direction, pieces of wood of the exact thickness of the planking are placed between the blades and secured by the pressure of the side screws.

By Mr. Brunel's method of fixing and tightening saws, a number of saws can be quickly removed from the frame and a new set of sharpened ones put in. To each end of each saw pieces of metal in the form of hooks are riveted. The hook at the lower end of the saw falls into a recess in the lower cross bar of the frame, and the upper hook is engaged with the hook of a shackle or link which hangs upon the upper cross bar, and has wedges through it by means of which it can be drawn tight for the purpose of straining the saw. As the tension of the different saws is uncertain when the wedges of the shackles are merely driven in by a hammer, a steelyard is employed, which not only shortens the time for driving up the wedges, but shows the amount of tension given to the saw. It consists of a strong axle extended across the fixed frame in which the saw-frame slides, and above the top of this frame, from one side of this axle, a lever proceeds with a weight attached to the end, and from

(1) In the "History of Inventions," is an interesting paper on *saw-mills*, with some speculations on the origin of the saw.



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the opposite side of the axle proceed two short levers connected by links to a strong cross bar, situated just over the upper cross bar of the saw-frame when at its greatest point of elevation. This cross bar of the steelyard has a link or shackle upon it which can be united by a key with any of the shackles upon the upper cross bar of the saw-frame, which shackles are united by the hooks with the upper end of their respective saws; and by this means the lever, with its weight, becomes a steelyard to draw up any one of the saws with a determinate force. In using this apparatus, the band or strap of the crank shaft is cast off to stop the motion of the saw-frame, the crank is turned round to elevate the frame to the highest point; two wedges are then put in between the saw-frame and a fixed part of the stationary frame, and this holds the saw-frame while the steelyard is applied, otherwise it would tend to strain the crank and crank-rod. The sharp saws are now put into the saw-frame, by hooking them upon the lower cross bar and uniting the hooks to the shackles on the upper cross bar, and pieces of wood are put between the saws according to the gage of the wood intended to be sawn, and bound fast by screws. The loaded end of the steelyard is now lifted up by a rope passing over a pulley, and the link upon the cross bar of the steelyard is united with the shackle of one of the saws: then, by allowing the steelyard to descend, it stretches the saw, and the wedge being thrust in by hand as far as it will go, thus retains the saw at the tension to which the steelyard had stretched it. The shackle of the steelyard is then disengaged from the saw, and removed to the next, and thus in turn all the saws are strained more equally than can be effected by simple wedges.

Returning now to the steel engraving, I I are cast uprights, bolted firmly to the floor of the mill, which is not shown in order not to interfere with the mechanism. These uprights carry at their upper part horizontal rollers, upon which the timber is moved while passing through the mill. The timber is fastened at one end to a carriage attached to the rack L, and at the other to a carriage which can be adjusted according to the length of the timber to be cut. M is a rack by which the timber is moved on during the action of the saw by the following contrivance. N is a horizontal lever turning upon the point N, and receives a slight reciprocating motion from an eccentric *g* upon the crank shaft during the stroke of the saw, but in a reverse direction, so that while the saw descends, the end of the lever rises: *h* is a small arm attached to the lever in such a way as to engage the teeth of a large ratchet-wheel O O while the motion is upwards, but in its descent simply passes over them without giving motion to the wheel. It has a small counterweight *n*, which causes the end of the arm to press gently against the teeth of the ratchet-wheel *m*, in order that in its return it may not fail to engage them. It will then be readily seen, that during the descent of the saw, which is the time its action takes place, the lever N, by means of the eccentric, is moving the ratchet-wheel round, from which, by a small pinion *p* upon its axle, which engages the teeth of the rack M M, the carriage and timber are moved gently forwards towards the saw.[1] The turning point of the lever N N can be adjusted to any part of it within the point *i* where the eccentric rod is fastened, so that any degree of motion can be given to the timber according to the nature of the wood to be cut. P P is a guide for the timber while passing the saw-frame: it causes the timber to move in a direction parallel to the motion of the saw. The timber is pressed against the guide by means of a lever, one end of which is connected with a weight over a pulley, and the other to a roller, which is pressed by means of the weight against the timber, and keeps it in its proper position with respect to the saw. When the timber has passed the saw, the carriage is returned by means of a handle *m* upon the spindle of the ratchet-wheel and pinion, which is worked by a man; the click being of course thrown up clear of the teeth to allow of its motion in a reverse direction. In some mills this is effected by the engine; but a man can easily run it back in less than a minute.

Two deals are usually sawn at one time, so that the parts described are in duplicate, and in the engraving one deal is removed in order the better to show the mechanism. Each deal is usually cut into 3 boards, in which case two saws are arranged on each side of the frame. In some cases as many as 11 thin saws or webs are used, thus producing from each deal 12 thin boards or *leaves*.

The single saw-frame makes from 100 to 120 strokes per minute, each stroke being 18 to 20 inches long, and two 12-feet deals are cut in from 5 to 10 minutes. For hard deals the saws require to be sharpened about every tenth *round* or journey; and about every twentieth round for fine. The frames are also made double so as to cut 4 deals at a time, in which case a double crank is used, so arranged, that while the saws in one frame are descending those in the other are ascending. The effect of this arrangement is to diminish vibration and to allow the velocity to be increased to 160 to 200 strokes per minute: but there is not much gain on this account, since a longer time is required for fixing and adjusting.

CIRCULAR SAWS. Various applications of the circular saw are given in the account of Brunel's block machinery [See BLOCK], and also in the notice of the sash-bar machine. [See INTRODUCTORY ESSAY, Fig. xl.] We shall also have to describe it under VENEERING. The applications of the circular saw are, however, so numerous that it would not be possible to give even a list of them within the remainder of our limits.[2] There is considerable doubt as to the date of the introduction of the circular saw; [See INTRODUCTORY ESSAY, p. cxlii.] Circular saws for cutting the teeth of water and clock wheels have been in use

(1) In the plank-frame invented by Mr. Benjamin Hick, of Bolton, there is no long rack; but each deal is grasped between two grooved feeding-rollers, the one fixed to the framing of the machine, the other pressed up by a loaded lever, and moved a single step at a time by a ratchet-wheel.

(2) The reader interested in the subject is referred to the chapter in Holtzapffel's "Mechanical Manipulation," already quoted.

since the time of Dr. Hooke: and the application of the wood-cutter's saw in the form of a revolving disc has been by some writers claimed for General Bentham. In 1805, Brunel took out a patent for sawing timber by means of a large circular saw, composed of several pieces fitted together by screwing them to a large flange turned perfectly true and forming part of the axle of the saw.

The method of constructing, sharpening and setting circular saws is very similar to that employed for rectilinear saws. In the planishing or hammering, the cutting edge of both kinds of saw, but especially the circular, should be made denser than the other parts: it should be made *tight* or *small* as it is called, and the amount of expansion produced by friction will then enlarge the edge so as to bring the saw into a state of uniform tension. If the edge of the saw be as wide as the other parts, the heat excited by friction when at work will cause it to vibrate from side to side, producing an irregular cut and a flanking whip-like noise, arising from the buckled parts of the plate in passing through the saw-kerf. The teeth of circular saws are in general more *distant*, more *inclined* and more *set*, than those of rectilinear saws. They are more distant on account of the greater velocity given to the saw, whereby the teeth follow in such rapid succession that the effect is almost continuous. They are more inclined because such teeth cut more keenly, and the extra power required to work them is readily applied. The harder the wood, the smaller and more upright should be the teeth, and the less the velocity of the saw. The teeth are more set in order to produce a wider kerf, since the large circular plate cannot be made so true, nor keep so true as the narrow straight blade. The setting must be very uniform, as one tooth projecting beyond the general line will score or scratch the work. "It is generally politic to use for any given work a saw of as small diameter as circumstances will fairly allow, as the resistance, the surface friction, and also the waste from the thickness, rapidly increase with the diameter of the saw. But on the other hand if the saw is so small as to be nearly or quite buried in the work, the saw-plate becomes heated, the free escape of the dust is prevented, and the rapidity of the sawing is diminished." As a general rule the diameter of the saw *s* Fig. 1920,* should be about 4 times the average thickness of the wood w; and the flange on the

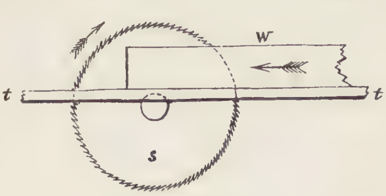


Fig. 1920.*

spindle should be as nearly as possible flush with the platform or saw-table *t t*.

In cutting with the grain, the teeth of the saw should be coarse and inclined, and the speed moderate, so as to remove shreds rather than sawdust. In cutting across the grain the teeth should be finer and more upright, and the velocity greater.

Crown saws. The *trephine* saw of the surgeon, which is said to have been known in the time of Hippocrates, has given rise to a large number of similar saws of various sizes, and under different names, such as *annular*, *curvilinear*, *drum* and *washing-tub* saws. Small saws of this kind, mounted upon the lathe, are used for cutting out discs of metal and wood. In the block machinery at Portsmouth the sheaves are cut out by means of the crown saw [See Block]. At some saw mills, crown saws 5 feet in diameter and 15 inches deep are used: they are constructed of 3 or 4 pieces of steel riveted to the outside of a strong ring which is fixed to the surface-chuck of a kind of lathe mandrel, and the work is grasped in a slide rest which traverses within the saw parallel with its axis. Large saws are used for cutting out the felloes of wheels and similar curved works; saws about 2 feet in diameter are used for cutting the round backs of brushes, the sloping hollow backs of chairs, &c. The edges of the staves of casks have also been cut by these saws before the staves were bent.

SCAFFOLDING, a temporary erection of timber for the purpose of supporting the workmen and the materials during the erection of a building. The bricklayer's scaffold is formed of fir poles, each 40 or 50 feet in length, and 6 or 7 inches in diameter at the butt ends which are securely fixed in the ground. Additional length is gained by lashing the top and butt of two poles together, and tightening the lashing by driving in wedges. These standards are united by means of horizontal poles placed parallel to the walls and called *ledgers*: they serve to support cross pieces called *putlogs*, made of birch, each about 6 feet in length, one end resting in the wall and the other on a ledger. The scaffold boards are supported by the putlogs: these boards are hooped at the end to prevent them from splitting.

As putlog holes cannot be allowed in masonry, the mason's scaffold is formed with two rows of standards so as not to require the support of the walls. But it is now usual in large works to form the scaffolding of square timbers connected by bolts and dogirons. The materials are hoisted by means of a travelling crane, consisting of a double travelling carriage running on a tram-way formed on stout sills formed on the top of two parallel rows of standards. The crab-winch is placed on the upper carriage, and by the double motion of the two carriages can be readily brought over any part of the work situated between the two rows of standards. [See Crane.]

The scaffold or *centering* used in building arches is noticed under Bridge, Section III.

SCAGLIOLA—See Mortars and Cements—Stone, artificial.

SCALE, a line drawn upon wood, ivory, &c., and divided into parts, the lengths of which may be taken off by the compasses and transferred to paper. The usual method of forming scales is by copying a carefully prepared original. See Graduation.

SCANTLING, a term applied to small timbers, such as the quartering for a partition, rafters, purlines, &c. All quartering or squared timber under 5 inches square is so called: the term is also used to express the transverse dimensions of a piece of timber.

SCARFING—See CARPENTRY.

SCHEELE'S GREEN—See ARSENIC. The apple-green pigment, so called, is prepared by dissolving 2 parts of sulphate of copper in 44 of hot water, and gradually adding to it a solution of 2 parts of carbonate of potash and 1 of arsenious acid in 44 of hot water, the whole to be well stirred during the mixture. The precipitate is to be washed, and dried at 212°.

SCHIST, a term sometimes applied to *slate*, but more properly limited to those rocks which do not admit of indefinite splitting like slate, but only of a less perfect separation into layers or laminæ; such are gneiss, mica-schist, chlorite-schist, talcose-schist, &c. The schists are fundamentally silicates of alumina; but they are so much mixed with such minerals as sand, mica, chlorite, talc, hornblende, actinolite, &c., as to form distinct varieties.

SCHWEINFURTH GREEN, a similar precipitate to that described as SCHEELE'S GREEN, but of a finer colour. 50 lbs. of sulphate of copper and 10 of lime are dissolved in 20 gallons of vinegar, and a boiling hot solution of arsenious acid is quickly stirred into it: the precipitate is to be dried and reduced to a fine powder. Both this and Scheele's green are very poisonous: they have nevertheless been employed in colouring sweetmeats.

SCISSORS. See CUTLERY.

SCRATCH-BRUSH, a cylindrical bundle of fine steel or brass wire, bound tightly in the centre with the ends projecting at both extremities, so as to form a stiff brush for cleaning and scratching metals preparatory to gilding and silvering. These brushes are sometimes made in the form of wheels, in which case the ends of the wires are a little curved, to prevent them from meeting the work too abruptly.

SETTING, OF RAZORS, SAWS, &c. See CUTLERY—SAW.

SCREW. Screws are of two kinds—*convex*, also called *external*, or *male*, and *concave*, also called *internal* or *female*. The first kind consists of a solid cylinder of wood or metal, on the surface of which is a projecting rib, fillet, or *thread*, passing spirally round so as to make equal angles with lines parallel to the axis of the cylinder. The second kind of screw consists of a cylindrical perforation through a solid block, the surface of the perforation bearing a spiral groove, corresponding to the thread on the solid cylinder, which fits it, or to which it is adapted.

The screw is usually regarded as a continuous circular wedge. If a piece of paper in the form of a wedge be regularly wrapped round a wooden cylinder, the edge of the paper will represent the line or thread of the screw. The interval between the threads will vary with the angle of the wedge, and the screw will be *coarse* or *fine* according as this angle is large or small. The screw will be a *right-hand* or a *left-hand* screw according as the wedge is wound upon the cylinder to the right hand or to the left. *Double triple*, or *quadruple* screws are those which have a double, triple, or quadruple thread, such, for example, as would be formed by placing 2, 3, or 4 strings in contact, and coiling them as a flat band round the cylinder. The screw may also vary in *section*, that is, the section of the worm or thread may be *angular*, *square*, *round*, &c. The screw may also vary in *diameter*. The degree of accuracy with which the screw is cut depends upon the purpose to which it is to be applied. *Binding* or *attachment* screws, used for connecting together the various parts of an object, do not require any especial care in their manufacture. *Regulating* screws, for guiding the slides and moving parts of machinery,—the screws of presses, for example, require a much higher degree of accuracy. The highest degree of excellence within the reach of the mechanician is required in *micrometrical* screws for graduating the right lines and circles and the scales of astronomical and mathematical instruments. [See GRADUATION.]

Considering the screw to consist of two parts, the external and the internal, it is easy to see how the production of the one may lead to the production of the other. Thus, by filing two or more flat faces on the external screw, the angles left form a series of cutters; the screw is, in fact, converted into a tap, by which internal screws of corresponding size and form can be produced. One of these hollow screws becomes the means of regenerating any number of copies of the original external screw. The art, however, of originating screws, or forming the original screw from which the tap is cut is a somewhat difficult one, and the more so in proportion to the accuracy required. In the early attempts a wedge of paper was cemented to an iron cylinder, and the spiral line was cut through with a knife or thin edged file, and the groove was gradually enlarged until the screw was formed. After the invention of the turning lathe a pointed turning tool was used to assist the file. Before the introduction of the screw-cutting lathe, the following method of originating a screw, by a workman named Anthony Robinson, was adopted at the Soho works:—"The screw was 7 feet long, 6 inches diameter, and of a square triple thread: after the screw was accurately turned as a cylinder, the paper was cut parallel, exactly to meet around the same, and was removed and marked in ink with parallel oblique lines, representing the margins of the threads; and having been replaced on the cylinder, the lines were pricked through with a centre-punch. The paper was again removed, the dots were connected by fine lines cut in with a file, the spaces were then cut out with a chisel and hammer, and smoothed with a file to a sufficient extent to serve as a lead or guide. The partly-formed screw was next temporarily suspended in the centre of a cast-iron tube or box, strongly fixed against a horizontal beam, and melted lead mixed with tin was poured into the box, to convert it into a guide-nut: it then only remained to complete the thread by means of cutters fixed

against the box or nut, but with the power of adjustment, in fact, in a kind of slide rest, the screw being handed round by levers."[1]

Another method of originating a screw is to wrap a small wire in close coils round a larger wire, and to take an impression thereof between two pieces of hard wood. The hollow or counterpart thread thus indented serves as a guide in cutting the screw. Mr. Mallett, of Dublin, described the following plan in the *Mechanics' Magazine* for January, 1844:—" Two straight edges of equal length and width, and about $\frac{5}{8}$ths of an inch in thickness each, are to be secured on a table, parallel to each other, standing on their edges, and distant from each other by nearly the length of the cylinder upon which the spiral is to be marked. Between these there is also to be secured in a diagonal direction, stretching from one to the other, a third straight edge, formed of two slips of deal glued together, with a slip of straight thick Bristol board between them projecting $\frac{1}{8}$th inch at one edge. The entire height of the diagonal straight edge, when standing on the table, must be a shade more than that of the two other straight edges. The three pieces being then thus arranged, the edge of Bristol board is charged with printers' ink. Then, on causing the cylinder to roll over the edges of the two parallel straight edges in the direction of their length, the diagonal slip of inked Bristol board will trace a spiral upon the surface of the cylinder with very considerable accuracy." By substituting a curved edge for the inclined straight edge variable screws will be obtained.

Screws are also originated by indenting a smooth cylinder with a sharp-edged cutter placed across it at the required angle, the surface or rolling contact producing the rotation and traverse of the cylinder. "In the most simple application of this method, a deep groove is made along a piece of board, in which a straight wire is buried a little beneath the surface; a second groove is made nearly at right angles across the first, exactly to fit the cutter, which is just like a table-knife, and is placed at the angle required in the screw. The cutter, when slid over the wire, indents it, carries it round, and traverses it endways in the path of a screw; a helical line is thus obtained, which, by cautious management, may be perfected into a screw sufficiently good for many purposes. The late Mr. Henry Maudslay employed a cutter upon cylinders of wood, tin, brass, iron, and other materials, mounted to revolve between cutters in a triangular bar lathe; the knife was hollowed to fit the cylinder, and fixed at the required angle on a block adapted to slide upon the bar; the oblique incision carried the knife along the revolving cylinder. Some hundreds of screws were thus made, and their agreement with one another was in many instances quite remarkable; on the whole, he gave the preference to this mode of originating screws."[2] The screw is also originated by traversing the tool in a right line along a plain revolving cylinder. Sometimes the tool has many points, and is guided by the hand alone: at other times the tool has but one single point, and is guided mechanically, as will be explained hereafter in the screw-cutting engine.

The external screws which are used for fastening pieces of wood, or wood and metal together, are called *wood-screws*, and in Scotland *screw-nails*. The blanks for these screws were formerly forged by the nail-makers, they being nearly the same as countersunk clout nails, [see NAIL, Fig. 1489, No. 5], except that the ends are not pointed. The blanks were next made out of round rolled iron cut to the required lengths; the heads being formed by pinching them while red-hot between a pair of dies, and the threads were cut by means of a file. But the method of making screws now most commonly adopted is that witnessed by the Editor in a factory at Birmingham, and described in his work on the "Useful Arts and Manufactures of Great Britain," already referred to. In the first place, a coil of wire fit for making screws is arranged so that it can be drawn into a machine as it is wanted; pieces of the proper length are cut off, and one end of each is struck up to form the head, and the blanks thus produced are then turned out into a box. By a second operation, the blanks are taken separately and placed in a lathe, where the heads and necks are properly shaped, by turning and cutting away superfluous metal. Thirdly, the notch or nick in the head of the screw for receiving the screw-driver is cut by means of a circular saw; the woman puts each screw into a kind of clasp, which holds it firmly, and then, by means of a lever, raises it to the cutter; the nick is formed in an instant,—the clasp is opened, the blank falls out, and another is inserted in its place, with great quickness. The teeth of the circular saws used in this operation, require filing up after every half-hour's work: for which purpose they are taken out, softened by heating and slowly cooling, then filed and sharpened, next hardened by heating and suddenly cooling; after which they are again fit for use. Fourthly, the blanks are ready for *worming*, as the operation of cutting the thread is called. This is done in a lathe; and as the blank requires to be held therein very steadily, the nick just formed is made to assist in doing so. The arrangement is shown in Fig. 1921:—A steel spindle or mandril revolves between collars in two uprights, by the motion of a strap passing round the pulley, *f*: *l* is a loose pulley to carry the strap when it is required to stop the machine. At *b* is an iron box made to hold firmly

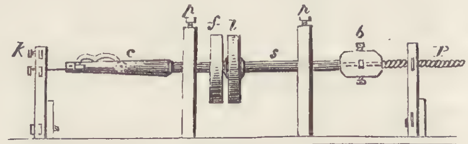


Fig. 1921.

(1) Gill's Technological Repository, vol. vi. Mr. Holtzapffel thinks it probable that a gun-metal nut was cast upon this screw, for use, after the screw was finished.

(2) Holtzapffel. "Mechanical Manipulation," vol. ii. The Chapter on the Screw in this work is of great value; it extends beyond 100 pages, and is illustrated by 109 wood engravings.

the pattern or regulating screw, P. This screw is 5 or 6 inches in length, and is an exact pattern of the thread of the screw to be cut, so that a fresh pattern or regulating screw is required for every variety of screw. The screw to be cut is fixed in an iron chuck or holder *c*, (also shown separately in Fig. 1922,) and is held firmly by a kind of hasp, the nick of the screw resting against a chisel spike, and the

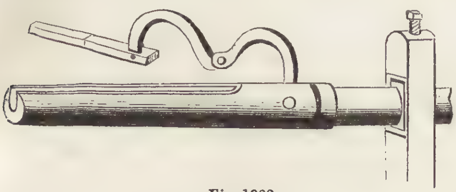


Fig. 1922.

shank projecting. The cutters are arranged in the frames at *k*: and are shown on a larger scale in the following figure. These frames move on joint pins,

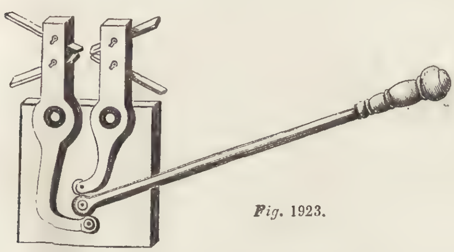


Fig. 1923.

and by the operation of the lever the cutters are made to act upon the shank of the screw, and to exert a greater or less degree of pressure, according to circumstances. There is also a lever which causes certain directing points, resembling the cutters, to close upon the regulating screw P, and the two levers being connected by a horizontal bar, can be depressed or raised together, and the cutters and directors applied at the same moment. In this way the inclination of the thread is determined by the pattern screw, and its shape by the form and position of the cutters.

This arrangement being understood, the order of proceeding is as follows:—The workwoman fixes a blank in the chuck; she next transfers the strap from the loose to the fixed pulley, thereby causing the chuck to revolve; she then depresses the levers, and the guides, acting upon the regulator screw from behind, cause the chuck to move forward and force the shank of the blank screw between the cutters, which turn out a shaving of metal, leaving a sharp thread or worm. The heat occasioned by this operation would soon destroy the temper of the steel cutters were they not kept cool; for this purpose, while the woman holds the lever down with one hand, she takes up with the other a piece of wood, dips it in water, and applies it to the tools. When the thread is traced far enough, the levers are raised, the chuck falls back, and the screw is released. Another screw is inserted in its place, and thus the cutting or tapping proceeds.

Screws are also cut by dies instead of cutters. The dies are arranged on a frame, and are opened and shut by a right and left-handed screw. As the dies regulate the size of the thread, there is no pattern screw, and of course the dies require to be changed for every variety of screw intended to be cut. Mr. Ryland's gimblet-pointed screws are thus made. This screw enters the wood easily and retains its hold firmly, and it is not liable to break where the thread ends, which the common screw will often do, especially in hard wood.

Mr. Nettlefold's patent screws are also made on a similar principle. In them great attention is paid to the thread, the upper side of which is very flat or inclined, which causes a great resistance to its being forcibly pulled out of the wood; while the under side is considerably inclined, which enables it to go into the wood with great ease, and rendering it unnecessary, in soft elastic woods, to bore a hole for its reception. The form of this screw, and its action upon the wood, will be better understood from the following figures,

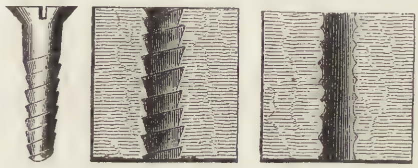


Fig. 1924. *Fig.* 1925. *Fig.* 1926.

in which Fig. 1924, represents the screw; Fig. 1925, the mould made by it in wood; and Fig. 1926 is a section of the common form of screw, in which the worm is shallow and imperfect. "The chief defects of common wood screws, besides bad threads, are the having, at the termination of the worm, a projecting bur, which is apt to tear away the wood before it, and leave little or no solid matter for the screw to hold by; the nicks in the heads being too shallow, or highest in the middle, preventing the screw-driver from taking an efficient hold to turn them in and out."

Screw bolts and other screws for working in metal are cut by a die resembling a common iron nut; it is formed of well-tempered steel in two parts, which are fixed in an iron box or *die-stock*, with two long handles or levers, as in Fig. 1927, and there is also a set screw, *s*, by means of which the 2 halves of the die may be brought nearer together or removed from each other. The blank or iron pin on which the screw is to be cut, having been turned to the proper size is introduced by its narrow extremity into the dies, which are then closed so as to grip the pin with tolerable force. The pin is set in a vice, and the die is worked round upon the pin by means of the two handles, and when a tolerably good impression of the thread is made upon the pin the two halves of the die are set closer together, and the operation is repeated whereby the thread is more defined, and it is cut deeper by setting the dies still more closely together. In such a case the worm is not formed by merely cutting away the metal, but partly by compressing it and squeezing it up, as it were, into the thread. In cutting such a thread by machinery the dies are in 4 pieces, the die-frame is fixed and the bolt or screw pin is made to revolve.

The die-stocks in common use are known as *double chamfered* and *single chamfered*. In the former about one-third of the length of the chamfer is filed away at one end for the removal of the dies laterally, and one at a time, and the aperture is about as long as 3 of the dies. In the single chamfered die-stock, the aperture is about as long as 2 of the dies, and these are removed by first taking off the side plate P, Fig. 1927, which is either attached by its chamfered edges as a slide, or by 4 screws, which when loosened allow the plate to be slid endways, when the screws escape from the grooves at *g*, and the screw heads from the holes *h*. The single chamfered

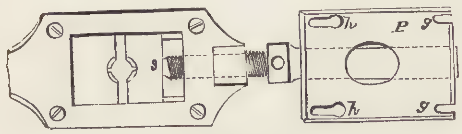


Fig. 1927

die-stock is preferred for large threads. The form of the die-stock is liable to much variation, but this is not of great importance provided the dies are accurately fitted. "In general only two dies are used, the inner surface of each of which includes from the third to nearly the half of a circle, and a notch is made at the central part of each die, so that the pair of dies present 4 arcs and 8 series of cutting points or edges, 4 of which operate when the dies are moved in the one direction, and the other 4 when the motion is reversed; that is, when the curves of the die and screw are alike." The most usual form of dies is shown in Fig. 1928, but as Mr. Holtzapffel remarks, "if every measure be taken at the mean as in this figure, the tool possesses a fair

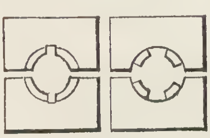


Fig. 1928.

average serviceable quality; that is, the dies should be cut over an original tap of medium dimensions, namely, one depth larger than the screw."

Small metal screws are cut by a steel *tap-plate* or *screw-plate*, Fig. 1929, wormed and notched, but furnished with several holes varying slightly in size, and the worm is formed progressively by using holes gradually diminishing in size. From 2 to 6 holes are

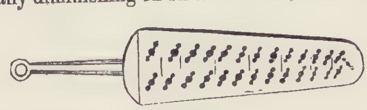


Fig. 1929.

intended for each thread, and are arranged in groups for the purpose as indicated by the short lines shown in the figure. The cutting edges are formed by making 2 or 3 small holes, and connecting them by the lateral cuts of a thin saw. In making the screw the wire should be fixed in a vice, the end tapered off, and after being moistened with oil screwed into the holes of the plate in succession. Although the screw plate is sometimes used for common screws as large as from $\frac{1}{2}$ to $\frac{3}{4}$ inch diameter, it is better to use die-stocks for all screws exceeding about $\frac{1}{16}$ inch diameter.

In cutting large screws, especially when the thread is square, a steel cutter may be used with the die. In cutting long screws in wood a steel cutter is fixed in the female screw or *screw-box*, as it is called, shown in section Fig. 1930, and in plan Fig. 1931, through the line *a*, and is thus described by Mr. Holtzapffel:—"It consists of two pieces of wood, accurately attached by two steady pins and two screws, so as to admit of separation and exact replacement: the ends of the thicker pieces are frequently formed

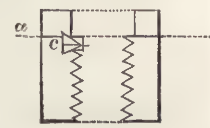


Fig. 1930.

into handles by which the instrument is worked. A perforation is made through the two pieces of

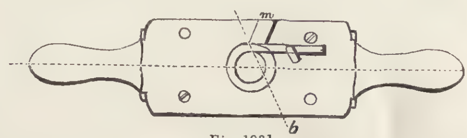


Fig. 1931.

wood; the hole in the thinner piece is cylindrical, and exactly agrees with the external diameter of the screw or of the prepared cylinder; and the hole in the thicker piece is screwed with the same tap that is used for the internal screws or nuts. The cutter or V has a thin cutting edge sloped externally to the angle of the thread, usually about 60°, and thinned internally by a notch made with a triangular file; the cutter is inlaid in the thicker piece of wood and fastened by a hook-form screwbolt and nut. In placing the cutter form different conditions require strict attention. Its angular ridge should lie as a tangent to the inner circle; its edge should be sharpened on the dotted line *b*, or at an angle of about 100° with the back; its point should exactly intersect the ridge of the thread, in the box; and it should lie precisely at the rake or angle of the thread, for which purpose it is inlaid deeper at its blunt extremity. The piece of wood for the screw is turned cylindrical and a little pointed: it is then twisted into the screw box, the cutter makes a notch which catches upon the ridge of the wooden worm

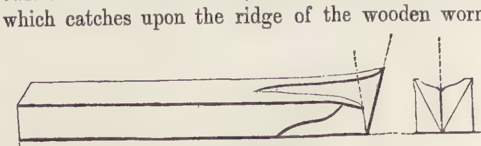


Fig. 1932.

immediately behind the cutter, and this carries the work forward exactly at the rate of the thread. The whole of the material is removed at one cut and the shavings make their escape at the aperture or mouth *m*." The cutter is shown in Fig. 1932.

Screws of half an inch diameter and upwards are fixed in the vice and the screw box is handed round like the die-stock: but for large screws exceeding 2 or 3 inches in diameter, two of the V's or cutters are placed in the box so as to divide the work and lessen the risk of breaking the keen edge of the cutter. The

screw box is used for wooden screws of 4, 6 and 8 inches diameter, but these large screws are now seldom made, metal screws having taken their place.

A steel tap is used for cutting interior screws, as already noticed. This tap is commonly a screw with a considerable portion of the worm removed by filing two or more flat faces along its whole length, the angles left by the operation forming a series of obtuse cutters. The tap is made somewhat conical in order to enter the hole with facility and cut the worm gradually. A tap is shown in 3 views in Fig. 1933. Two taps are in some cases used, only the first of

Fig. 1933.

which is tapered. The head of the tap is square, for fitting into the middle of a long handle or tap-wrench which is used for working it into the nut. The taps for cutting screws in wood are usually fluted at the side to allow the cuttings to escape.

The simplest form of tap is produced by filing 4 planes upon the screw, as in Fig. 1834, *a*; but the edges thus produced are very obtuse, and form the thread rather by raising or burring up the metal than by cutting. A better form for cutting is obtained by filing only 3 planes on the screw as in *b*, but even then the angle is as great as 120°. Taps of very small size cannot well be formed of a more favourable section; but for general purposes the best angle for the edges of screw taps and dies is the radial line or an angle of 90°. Sir John Robison obtained such an angle in his half round tap *c*, and he states that such a tap "will cut a full clear thread, even if it be made of a sharp pitch, without making up any part of it by the burr, as is almost universally the case when blunt edged or grooved taps are used." Mr. Holtzapffel remarks that when two-thirds of the circle are allowed to remain as in *d*, this, "although somewhat less penetrative than the last, is also less liable to displacement with the tap wrench. It is

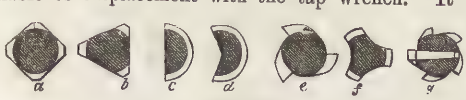


Fig. 1934.

much more usual to employ 3 radial cutting edges instead of one only; and as in the best forms of taps, they are only required to cut in one direction, or when they are screwed *into* the nut, the other edges are then chamfered to make room for the shavings, thereby giving the tap a section somewhat like that of a ratchet wheel, with either 3, 4 or 5 teeth," as in *e* and *g*. "It is more common, however, to file up the side of the tap or to cut by machinery 3 concave or elliptical flutes as in *f*; this form sufficiently approximates to the desideratum of the radial cutting edges, it allows plenty of room for the shavings, and is easily wiped out. What is of equal or greater importance, it presents a symmetrical figure, little liable either to accident in the hardening, of distortion from unequal section as in *c* and *d*, or of cracking from internal angles as in *d* and *e*." Mr. R. Jones has contrived a tap in which a steel cutter can be inserted as shown in *g*: the cutter is made to project a little, so that the tap follows it without difficulty. Mr. Gill has described a tap for cutting a square threaded screw: it consists of a hollow steel screw with a hole drilled obliquely from the front end of the thread to the hole in the centre of the tap: the edges of this oblique hole are sharp, and cut their way through the wood, while the hole forms a passage for the escape of the shavings. Mr. Siebe's tap for cutting right hand or left hand internal screws in wood, according to the direction in which it is turned, is represented in Figs. 1935, 1936. The tap is formed by

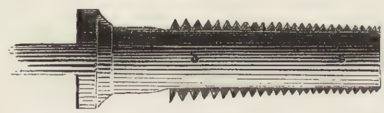


Fig. 1935.

Fig. 1936.

turning a wooden screw of the required size, cutting a longitudinal slit along its centre, and inserting a plate of steel of the length and breadth of the screw: the edges of this plate are now filed into notches corresponding with the worm: the plate is then removed and the wooden thread is turned away, leaving the wood in the form of a plain cylinder. The steel plate is then reinserted and firmly secured, as shown in the figures, which give a side and an end view of the tap. The steel plate is made to taper a little, so as to ensure a gradual cutting action. A groove cut on each side of the plate, affords a channel for the escape of the turnings: the upper end of the cylinder is made square for the insertion of the wrench. Such a tap may also be formed without the assistance of the worm on the stock, simply by notching the steel plate, taking care that a tooth on one side shall coincide with a hollow on the other. Mr. Siebe proposes similar taps with only two cutting edges, for cutting screws in metal.[1]

SCREW-CUTTING ENGINE. In the method of cutting screws by the lathe as already described, the pattern screw regulates the pitch of the thread, and screws of different make require each its own pattern. In the Woolwich Dockyard is an engine for cutting large screws accurately to any required pitch, from one pattern. This engine is represented in elevation and plan in the steel engraving.[2] A B, Fig. 1, is one side of a cast-iron lathe-bed, both sides of which are represented in Fig. 2. P Q are two cast-iron puppets. C D an axle turning on a point at C, its end being countersunk to receive the point, the other end bearing on a slightly conical collar in the puppet Q. The 2 bevelled wheels W W′ fit one part of the axle, and either of them may be thrown in or out of gear with the other bevelled wheel W″, Fig. 2, which is turned by the steam-engine shaft. On the side of the bed are 2 standards S S, in which the screws *s s* turn in

(1) Transactions of the Society of Arts, vol. xli.

(2) We are indebted to the volume on "Manufactures," in the Encyclopædia Metropolitana, for the drawings and descriptions of this engine.

collars, both screws being seen in Fig. 2. E is a sliding frame with a nut on each side, through which the screws *s s* pass, so that as the screws revolve, this sliding frame is carried from one end of the bed to the other, and in this frame is fixed the tool for cutting the threads of the screw. The cutter is secured in its proper position by means of plates and nuts, Fig. 2. Another cutter may be fixed on the opposite side, so that one cutter may act while the slide *r* is passing from A towards B, and the other as it returns from B to A. This plan, however, does not produce very good results in practice, so that one cutter only is employed, and the carriage returns free. The cutter is adjusted to its proper place by the screw and lever *c d*. T V is a sliding puppet carrying the back centre: this puppet may be placed in any part of the bed, and there screwed fast, while any small adjustment for distance may be made by the screw G, Fig. 2. The bolt or cylinder on which the screw is to be formed being turned perfectly true to two centres, one at each end; this is applied to the points in the mandrel and back centre, and a proper degree of contact is attained by the screw G. The end of the cylinder next to the mandrel D is properly secured: an iron chuck is placed on the mandrel, and rotation is given to the cylinder by means of the driver, and in this form it may be used for any purpose in which a powerful lathe is required. But for cutting screws, a wheel *w* is fixed on the mandrel, and 2 equal wheels on the ends of the screws *s s*, so that while the cylinder revolves by means of the power communicated to the bevelled wheel by the engine, the wheel *w* gives rotation to the wheels *w′ w″*. A horizontal motion is thus given to the slide-rest or sliding frame from one end of the bed to the other, and the cutter being pushed forward by means of the screw, a first impression of a thread is formed in the revolving cylinder. When the frame arrives at the end of the cylinder, it presses on the stud *n* on the lever *l*, and throws the wheel out of gear. The tool is then brought back, the motion is reversed by bringing the other bevel wheel in gear, and the cutting frame returns. The wheel is now thrown out of gear by the frame itself, as at the other end; the tool is readjusted and made to cut deeper, and thus the operation is repeated until the screw is completed.

If the screw to be cut is to have the same pitch as the permanent screw which carries the slide-rest, the 3 wheels *w*, *w′*, *w″*, are all equal to each other, so that one revolution of the axle advances the cutter one thread; but by changing these wheels, so that the wheel *w* exceeds or falls short of the other two in any ratio, the thread of the new screw may be made to differ from those of the permanent screw in the same ratio. Screws of any required pitch may, therefore, be cut by having a variety of wheels so arranged that the sum of their two radii shall be a given quantity.

For cutting a screw with a double thread, one thread is first cut, and then the driver is applied to a hole in the iron chuck directly opposite to its first position, by which means a semi-rotation is given to the new screw without producing any motion in the cutting frame, and consequently the cutter is now applied to a point midway between the two former threads, when by the same process as before this intermediate thread may be formed. If a triple thread be required, the driver is applied to a hole in the chuck, which is distant from its original position one-third of a circumference, and then again to another at two-thirds the distance, and in a similar manner any number of threads may be formed.

The apparatus for cutting the nut consists of a revolving cutter, turned on the principal axis while the nut itself is fixed in the slide-rest, so that while the cutter revolves in its place, the nut gradually advances upon it, instead of the cutter advancing upon the thread, as in cutting the screw.

The SCREW, as a mechanical power, will be noticed under STATICS.

SCREW OF ARCHIMEDES. A machine for raising water, invented by Archimedes: it is also called the

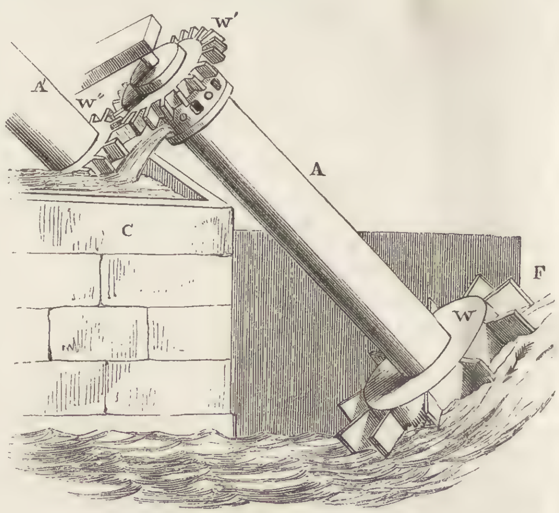


Fig. 1937. ARCHIMEDIAN SCREW.

spiral pump, and in Germany the *water-snail*. Its structure and application will be understood by referring to Fig. 1937, in which W is a wheel moved in the direction of the arrow by the fall of water F, which need not be more than 3 feet. The axle A of the wheel may be raised so as to make an angle of between 44° or 45° and 60° with the horizon, and on the top of the axle is a wheel W′ which turns a similar wheel W″, having the same number of teeth, the axle A′ of this wheel being parallel to the axle A of the two

Fig. 1938.

former wheels. The axle A is cut into a double threaded screw, Fig. 1938, which must be right-

Fig. 1.

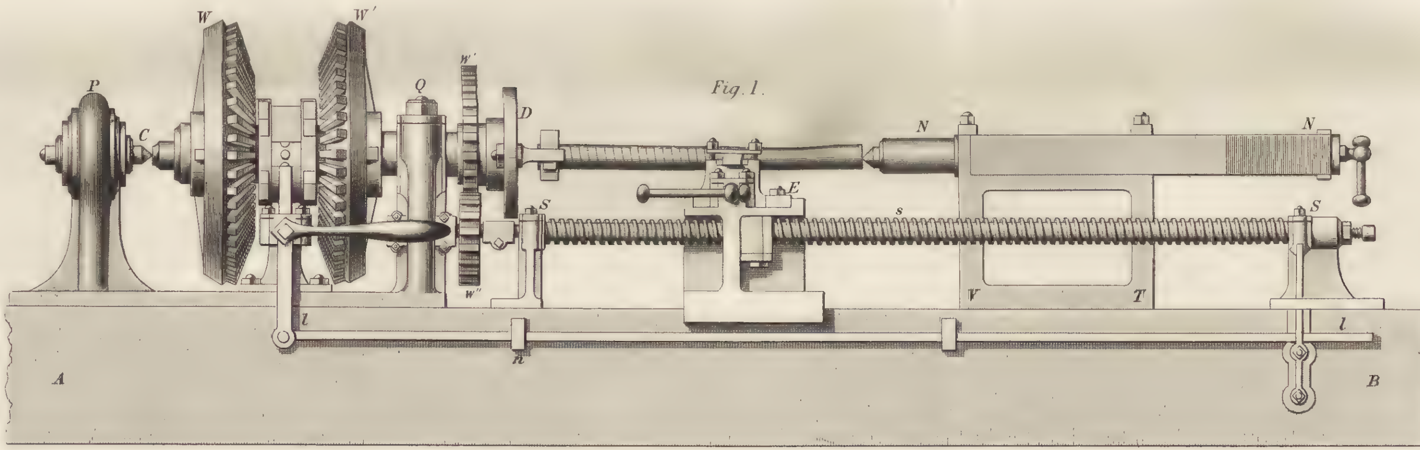
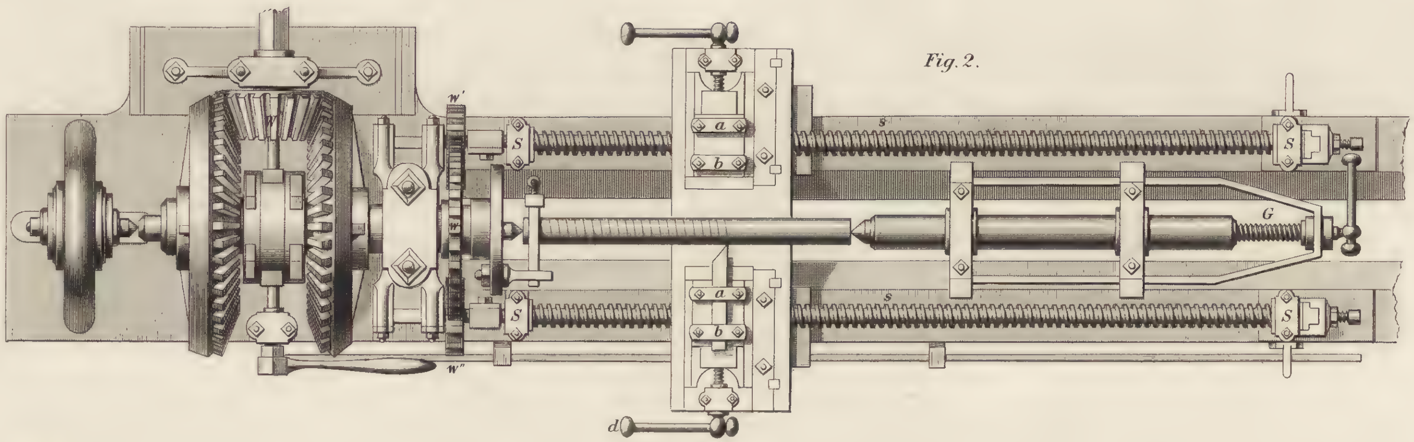


Fig. 2.



SCREW ENGINE FOR CUTTING LARGE SCREWS

handed if the first wheel is turned in the direction of the arrow, and left-handed if the stream turn the wheel the contrary way: also, the screw on the axle A must be cut the contrary way to that on the axle A′, because the 2 axles turn in contrary directions. The screws must be covered over with boards, and they will then form spiral tubes: or a tube of stiff leather may be wrapped round shallow grooves in the axle, as in Fig. 1939. The lower end of the axle A revolves constantly in the stream which gives motion to the wheel, and the lower ends of the spiral tubes open

Fig. 1939.

into the water, so that as the wheel and axle revolve the water rises in the spiral tubes, and makes its escape at the top through the holes *o o*, which are set in a broad close ring on the top of the axle, into which ring the water is delivered from the upper open ends of the screw tubes, and falls into the open cistern C. The lower end of the axle A′ turns on a gudgeon in the water in C; and the spiral tubes in that axle take up the water from C and deliver it into a similar cistern just below the top of A′, on which there may be such another wheel as W″ to turn a third axle by such a wheel upon it. In this way water may be raised to any given height provided there be a stream of sufficient power to act on the float-boards of the first wheel.

The *water-screw*, Fig. 1940, resembles the above, only the spiral projections are detached from the external cylinder within which the screw revolves.

Fig. 1940.

This want of perfect contact between the screw and the cover occasions a loss; and, in general, at least 1-third of the water runs back, and the axis cannot be placed at a greater elevation than 30°: it is also easily clogged by impurities in the water. When, however, the lower end is immersed to some depth in the water, it has been found to raise more water than the screw of Archimedes, so that if the height of the surface were liable to any great variations the water-screw might be preferred to the Archimedian screw.

The mode of operation of the screw of Archimedes is thus illustrated by Dr. Gregory, in his Treatise on Mechanics:—"If we conceive that a flexible tube is rolled regularly about a cylinder from one end to another, this tube or canal will be a screw or spiral, of which we suppose the intervals of the spires or threads to be equal. The cylinder being placed with its axis in a vertical position, if we put in at the upper end of the spiral tube a small ball of heavy matter, which may move freely, it is certain that it will follow all the turnings of the screw from the top to the bottom of the cylinder, descending always as it would have done had it fallen in a right line along the axis of the cylinder, only it would occupy more time in running through the spiral. If the cylinder were placed with its axis horizontally, and we again put the ball into one opening of the canal, it will descend, following the direction of the first demi-spire, but when it arrives at the lowest point in this portion of the tube it will stop. It must be remarked that, though its heaviness has no other tendency than to make it descend in the demi-spire, the oblique position of the tube, with respect to the horizon, is the cause that the ball, by always descending, is always advancing from the extremity of the cylinder whence it commenced its motion to the other extremity. It is impossible that the ball can ever advance more towards the further, or, as we shall call it, the *second* extremity of the cylinder, if the cylinder placed horizontally remains always immoveable: but if, when the ball is arrived at the bottom of the first demi-spire, we cause the cylinder to turn on its axis without changing the position of that axis, and in such manner, that the lowest point of the demi-spire on which the ball presses becomes elevated, then the ball falls necessarily from this point upon that which succeeds, and which becomes lowest; and since this second point is more advanced towards the second extremity of the cylinder than the former was, therefore by this new descent the ball will be advanced towards that extremity, and so on throughout, in such a manner that it will at length arrive at the second extremity by always descending, the cylinder having its rotatory motion continued. Moreover, the ball, by constantly following its tendency to descend, has advanced through a right line equal to the axis of the cylinder, and this distance is horizontal because the sides of the cylinder were placed horizontally. But if the cylinder had been placed oblique to the horizon, and we suppose it to be turned on its axis always in the same direction, it is easy to see that if the first quarter of a spire actually descends, the ball will move from the lower end of the spiral tube, and be carried solely by gravity to the lowest point of the first demi-spire, where, as in the preceding case, it will be abandoned by this point as it is elevated by the rotation, and thrown by its heaviness upon that which has taken its place; whence, as this succeeding point is further advanced towards the second extremity of the cylinder than that which the ball occupied just before, and consequently more elevated, therefore the ball, while following its tendency to descend by its heaviness, will be always more and more elevated by virtue of the rotation of the cylinder. Thus it will after a

certain number of turns be advanced from one extremity of the tube to the other, or through the whole length of the cylinder; but it will only be raised through the vertical height determined by the obliquity of the position of the cylinder.

"Instead of the ball, let us now consider water, as entering by the lower extremity of the spiral canal, when immersed in a reservoir: this water descends at first in the canal solely by its gravity; but the cylinder being turned, the water moves on in the canal to occupy the lowest place; and thus, by the continual rotation, is made to advance further and further in the spiral, till at length it is raised to the upper extremity of the canal, where it is expelled. There is, however, an essential difference between the water and the ball; for the water, by reason of its fluidity, after having descended by its heaviness to the lowest point of the demi-spire, rises up on the contrary side to the original level; on which account more than half one of the spires may soon be filled with the fluid."

SCREW-JACK, an instrument in common use for raising timber or heavy weights through short lifts. It consists of a powerful combination of teeth and pinions enclosed in a strong wooden stock or frame, B C, Fig. 1941, and moved by a winch or handle H P. In Fig. 1942 the rack-work is shown, the stock being removed. In the figure a very short rack is shown:

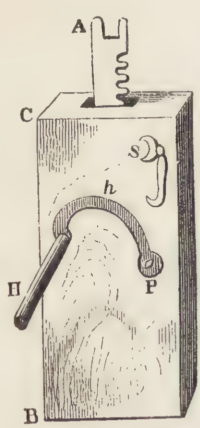


Fig. 1941.

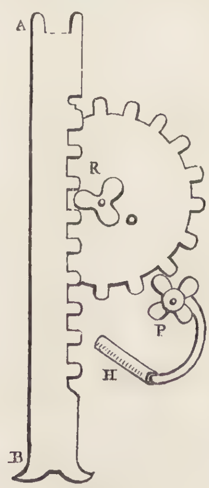


Fig. 1942.

it should be at least 4 times as long in proportion to the wheel O, and the teeth be 4 times more numerous, or have about 3 in the inch. If the handle H P be 7 inches long, the circumference of this radius will be 44 inches, which is the distance or space through which the power moves in one revolution of the handle; but as the pinion of the handle has but 4 leaves, and the wheel O, say 20 teeth or 5 times the number, therefore to make one revolution of the wheel O requires 5 turns of the handle, in which case it passes through 5 times 44 or 220 inches: but the wheel having a pinion R of 3 leaves, these will raise the rack 3 teeth or 1 inch in the same space; hence the handle or power moving 220 times as fast as the weight, will raise or balance a weight 220 times greater: and if a man's hand sustains 50 lbs. weight, he will be able, by means of this jack, to sustain a weight or force of 11,000 lbs., or about 5 tons weight. The machine is in some cases open from the bottom nearly up to the wheel O to allow the lower claw, which in such case is turned up as at B, to draw up a weight. When the weight is drawn or pushed to the required height it is prevented from going back by hanging the end of the hook S, fixed to a staple, over the curved part of the handle at *h*. The jack is also sometimes furnished with a pall and ratchet, to stop the motion of the machine as soon as it begins to run back.

SCREW PILE—See Lighthouse.

SCREW PRESS—See Card, Fig. 477—Printing.

SCREW PROPELLER—See Steam.

SCULPTURE, Mechanical processes of. Sculpture is the art of carving or cutting any material into a proposed form or shape, for the purpose—1, of representing entire figures, as in statues and groups, called by artists *the round;* 2, of making figures either in *high* or *low relief* (*alto* or *basso rilievo*), the object being more or less raised, but not entirely detached from the back ground; 3, of cutting or sinking into a ground, so as to make the object represented below the plane of the original ground. Sculpture is also defined as the art of representing objects by *form*, (in contradistinction to painting, in which *colour* is introduced,) and has thus been applied to *carving*, to *modelling* or the *plastic art*, to *casting* in metal, and to *gem-engraving* in hard and soft stones. [See Seal-Engraving.]

The materials used by the sculptor are very numerous, but probably more so in ancient times than at present. "For modelling, clay, wax, and stones or plaster, appear to have been universally used: the clay, after having been worked into the proposed form, was frequently baked, acquiring by that process a hardness not inferior to stone: in this state, too, it often served for moulds, into which soft clay was squeezed, and thus the object became easily multiplied. A considerable number of ancient specimens of statues, *bassi rilievi*, lamps, tiles, and architectural ornaments in this material (called *terra cotta*) have been preserved. Marbles, stones, and woods of all kinds, as well as ivory, were employed by the carvers, and all the known metals, wax, plaster, and even pitch, were used for the different processes of casting. There was a statue of amber of Augustus; and at the celebration of *Funeralia*, as in those of Sylla, at public exhibitions, or on other extraordinary occasions, we read of statues having been made of aromatics, and of materials of the most combustible nature; and amongst the odd conceits of the ancient artists, may be mentioned a statue of Venus, which attracted a Mars of iron. The combination of different materials for the purpose of producing variety of colours, either for drapery or ornaments, was termed *polychromic* sculpture (πολὺς, many, χρῶμα, colour), and those works which were composed of a variety of stone or marble were, in like manner, called *polylithic* (πολὺς, many, and λίθος, a stud). This mixture of materials, which modern taste disapproves, was continually

resorted to by the most celebrated artists during the best period of art in Greece, particularly in colossal works."[1]

As it would be quite impossible within our limits to describe the modes of working up all the materials enumerated in the above passage, we propose to notice briefly the mechanical processes adopted in the production of a work in marble. Many of the processes above alluded to are described under separate heads.

The sculptor first expresses his idea in a sketch on paper, and then makes a small model, generally in clay, or, for greater accuracy and perfection, a model of the size in which the marble, bronze, or wood, &c., is to be executed. The figure is first modelled naked, and in its proper action and form: he then lays on the drapery either from studies made after the living figure, or drapery placed on a lay figure or *mannikin.* The clay model, if large, is supported by a frame-work of iron, and the masses of clay are kept together by small wooden crosses attached to the iron frame-work, by wires of different lengths dispersed in different parts of the clay. The modeller's tools are of wood or ivory, with ends pointed, rounded, square, or diagonal, with which he forms his model, marks out the hollows and dark parts, and does whatever his unaided fingers cannot effect. The clay must be occasionally sprinkled with water to prevent the model from shrinking and cracking, and when left for some hours it should be covered with a damp cloth. The clay model being finished, it is moulded and cast in plaster, the plaster being supported by iron bars cemented, to prevent the rust coming through. The method of taking plaster casts is described under GYPSUM. If the work is to be executed in bronze, particular attention must be bestowed on the mould, to enable it to bear the weight of the fluid metal.

The model is copied in marble in the following manner:—A number of small black points are marked upon the model in every principal projection and hollow, so as to give the distances, heights, and breadths, sufficient for copying with the marble from the model. The ancients did this by considering every 3 points on the figure as a triangle, which they made in marble to correspond with the same 3 points in the model, by trying it with a perpendicular line or some other fixed point, both in the marble and the model. The modern method is this:—After having ascertained by rough measurement that the block of marble is sufficient to make the statue of the size of the model, it is fixed on a stone base or wooden bench, called a *banker*, in front of which is a long strip of marble divided into feet and inches. A similar strip is placed in front below the model, together with a wooden perpendicular rule the height of the whole work: this rule can be taken from the marble graduated scale under the model to the marble scale under the marble block. The rule being first placed upon the scale of the model, and the exact distance taken from it to any prominent part, as, for instance, the end of the nose, it is then removed to the corresponding position of the other scale, and the workman cuts away the marble to the same distance from the perpendicular at the same height; that is, until he has arrived at that portion of the block which is to form the tip of the nose. He then proceeds in the same way with some other prominent part, such as the top of the head, until at length he has produced a rough representation of the whole figure.

Machines have also been contrived for producing the same effect with greater convenience and rapidity. One of them, called a *pointing instrument*, consists of a pole or standard, to which a long brass or steel *needle* is attached, so as to admit of being extended and withdrawn, loosened or fixed, and moved in every direction by means of a ball and socket-joint. This instrument being made to touch a particular part of the model, it is removed to the banker, and the marble is cut away until the needle reaches as far into the block as it had been fixed at upon the model. A pencil mark is then made upon the two corresponding parts of the model and block, and *a point* is thus said to be taken. By a frequent repetition of the process, the various points at fixed depths, corresponding with the surface of the model, give a rough copy of the intended work. The work is sometimes performed by drilling. For example, the workman measures how far any particular part of his model, such as the tip of the nose, is from the front of the banker, and having found the proper position of the corresponding point of the block of marble, he drills a hole to the same depth from the front, as in the model. Other prominent points are, in like manner, measured, and holes are drilled to their proper depths from the front, until at length the block of marble presents a honeycombed appearance from the numerous drillings. The portions of marble between the holes are cut away with the chisel, care being taken not to chip away any of the stone below the drill-hole. Mr. Behnes has contrived an improved machine on this principle.

When at length the figure has thus been *roughed* or *blocked* out, the mechanical art merges into the fine art. The sculptor now takes the dead mass in hand, and imparts to it that artistic life which conveys to the beholder beauty of form, mental and anatomical expression, and a well-defined purpose. How this is done cannot be told in words. The mechanical aids are steel chisels, varying in breadth from an inch to a mere point, and for deep parts drills are also used. The sculptor goes over every part of the surface of the marble, urging the chisels with hammers of from 2 to 4 lbs. each. In this work, however, the sculptor is frequently assisted by a superior workman, called a *carver*, who knows by the pencil marks how far he can penetrate into the marble. After the chiselling the surface is gone over with rasps, and then with sharp files. The smooth parts are rubbed up with pumice-stone or grit-stone, cut to suit the various forms of the surface.

SEAL-ENGRAVING is the art of sinking, in intaglio, armorial bearings on gems and hard stones.

(1) Article SCULPTURE—Encyclopædia Metropolitana.

When the subjects are of a more artistic kind, the art is properly called GEM-ENGRAVING. When the design is engraved in relief, it forms a third division of the art, viz. CAMEO-CUTTING. All three branches have, however, in practice, a great affinity, and the tools and processes are similar in all. The tools are small revolving wheels, the edges of which are charged with a fine abrasive powder, applied by means of oil or water: the object to be engraved is held in the fingers of the artist, and thus applied to the lower edges of the small wheels, and is moved about into the positions favourable to the production of those fine lines, grooves, and hollows, which are in fact counterparts of the small wheels or tools themselves. For hard stones the wheels are of iron charged with diamond powder by means of oil of bricks, the polishing being performed by means of copper wheels charged with rottenstone and water. For engraving glass, similar but larger tools of copper are used, charged with emery and olive oil, the polishing being effected by means of leaden tools charged with pumice-stone and water.

All gems inferior in hardness to the diamond admit of being operated on by the seal-engraver, and even the diamond itself has been engraved. The sapphire is cut very slowly, but smoothly; the ruby is cut slowly, and is apt to break off in small flakes; carnelian and bloodstone are of close structure, and can be cut slowly. The softer stones can be cut with greater rapidity, but the effect is not so smooth as in the case of the harder stones. The amethyst is as soft a stone as can be engraved smoothly: when such soft substances as glass or marble are engraved, the tools soon become deteriorated in consequence of the diamond powder becoming imbedded in the material and reacting on the tool. Stones consisting of laminæ of different degrees of hardness require care in the cutting, to prevent the tool from sinking more deeply into the softer parts. When the device is seen from the surface in the colours of the lower stratum the seal is called a *nicolei*.

The seal engraver's *tools* are furnished with long conical stems for fitting into the hollow mandrel or quill of a small lathe head or *engine*, Fig. 1944, mounted on a table, Fig. 1943, which is hollowed out in front, and furnished below with a light foot-wheel for driving the engine with a steady motion. The engine, shown separately in section, Fig. 1944, is a brass pillar about 6 inches high, with a bolt at the bottom for passing through the bench, where it is retained by a nut. At the upper part of the pillar are two openings which cross at right angles: these are for the reception of the pulley and the bearings of the quill. The bearings are usually cylindrical, and are made of tin or pewter cast upon the quill, fitting it by a set screw, which passes through a brass cap at the top of the pillar. The quill is of steel, about 2 inches long and $\frac{1}{2}$ inch diameter: it passes through the bearings, and has two small beads upon it for preventing end play. The quill is hollow throughout its length, and slightly conical, and on one side of the perforation is a small groove, into which passes a feather on the tools, which prevents them from slipping round. The pulley is about $1\frac{1}{2}$ inch diameter, and is generally made in one piece with the quill.

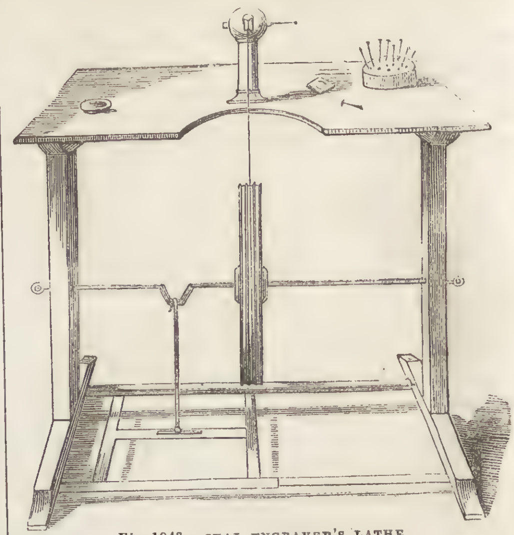


Fig. 1943. SEAL ENGRAVER'S LATHE.

The top of the pillar is covered with a small cap for keeping away dust and grit from the bearings, and is used as a rest for steadying the hand of the engraver. The tools are of soft iron wire carefully annealed. Around the stem of each tool is cast a conical plug of tin, pewter, or other soft metal, for fitting it into the quill of the engine. As it is of great importance that the tools should run true, they are fixed in the quill and turned to the proper forms: the rest for turning the tools is passed through a mortice in the brass standard. The forms of the tools are very various, but the general form is that of a small disk more or less rounded on the edges, which is the part used in cutting. For cutting fine lines the edge is nearly as thin as that of a knife: a thicker and more rounded edge is used for thicker lines. For sinking large shields the tools are considerably rounded, and in some cases almost spherical. The rounded tool cuts more rapidly than one with a nearly flat edge, and is commonly used for removing the chief bulk of the material, while the flatter edge is used for smoothing the surface. To allow the tool to be applied to sunken flat surfaces without the stem interfering with its action, the edge is made conical, as at *e*, Fig. 1945. The tools *b c d e* are seldom larger than $\frac{1}{8}$th inch diameter, and they are made so small as not to exceed $\frac{1}{150}$th inch diameter, when the tool can scarcely be distinguished by the unassisted eye from its stem. These very

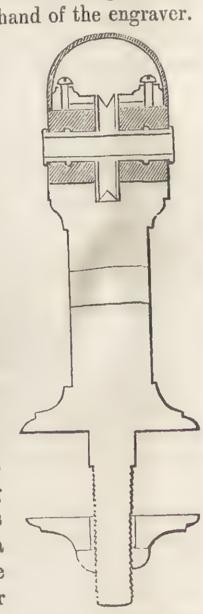


Fig. 1944.

small tools cannot be formed by the file alone; but when made as small as possible by that means they are used on works of larger size until worn down small enough to be used for making small dots and markings in the figures of men or animals, the full lengths of which are not more than ¼ inch. The

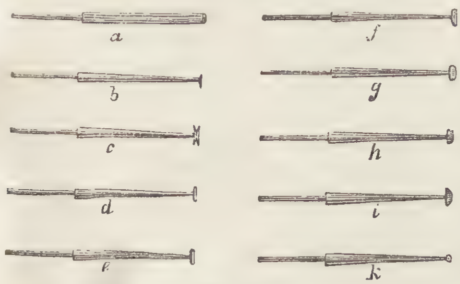


Fig. 1945.

surfaces of the tools must be smooth, *i. e.* free from *creases*, as the hollows are called, one of which, in a thin tool, such as *b* or *d*, will be likely to chip instead of cut. The formation of creases is prevented by the frequent use of a fine file.

The mode of preparing diamond powder is described under Lapidary-work, Fig. 1272. It is brought into a pasty condition by mixing with olive-oil, and the paste is kept in a small conical cup, which every now and then is applied to the tool, or the engraver may wear on the forefinger of the right-hand a ring made of a strip of tin, to which are soldered 2 little hollow discs about ½ inch diameter, one of which contains a very small quantity of diamond paste, the other 1 or 2 drops of the oil of bricks. The diamond paste is applied to the extreme edge of the tool while in slow motion: the tool is then moistened with the oil of bricks, and the cutting is proceeded with until the brick-oil is evaporated. The tool must not be allowed to become too dry, or the diamond paste would become detached from the tool, which would then be cut instead of the stone. Sperm-oil is sometimes used instead of brick-oil.

The stones to be engraved are brought to their general form by the lapidary, and are often set by the jeweller before being engraved. They are then mounted in a handle about 5 inches long and ¾ inch diameter. If the stone is not set, it is fixed with lapidary's cement upon a wooden handle, the cement being coated with sealing-wax to prevent the cement from adhering to the fingers. If the stone is set, it is inserted in a notch made in a piece of cork or bamboo. If the stone is hard and polished, the surface is roughened by rubbing it upon a soft steel plate charged with a little diamond powder and oil, or if the stone be soft, upon a leaden plate charged with emery. The tools are less liable to slip, and penetrate better on a rough than on a smooth surface: and the outline of the device can also be better sketched out upon the rough surface. The general outline is first carefully drawn upon the stone with a brass point: the entire surface within this outline is then sunk: the details of the design are next sketched in and sunk in succession. For forming an outline, the small tool *b*, Fig. 1945, is used; this is called a *sharp* or *knife* tool. The outline being dotted out with this tool, a thicker tool, with a rounded edge, such as *d*, may be employed for perfecting the outline: a thicker and larger tool, such as *f*, is next used for removing the bulk of the material within the outline. The surface, when sufficiently lowered, is smoothed or stippled with a smaller and flatter tool, such as *e*. In roughing out the work the engine is driven rapidly, and the stone applied with moderate pressure. A slower speed and a less pressure are used when the smaller tools are applied; and, with the smallest tools, such as are used for cutting the details, the pressure is slight, and the engine is driven still more slowly. Curved lines and rounded forms are, from the circular forms of the tools, more easily engraved than straight lines. Fine lines, with sharp curves, such as the hair-strokes in writing, are difficult to engrave; but the bolder lines, in German-text initials, are far more easy of execution. "The cutting of the fine parallel lines on the field, called *colour lines*, presents considerable difficulty, as they are very shallow, and to give them a uniform appearance requires much care, and a light but steady hand. To assist in cutting these lines equidistant, a tool is used, having 2 knife-edges, *c*, Fig. 1945, and called a *colouring tool*. The front edge of this tool is used to cut the first line to the required depth, and the second line is at the same time marked out by the back edge: at the next process the second line is cut to the full depth, while the third line is marked in the same manner, and so on; the lines being cut in succession from right to left, in order that the operator may be enabled to watch the progress of the tool throughout, and the stone is held in an inclined position to cause the greater penetration of the front edge of the tool."[1]

The engraver watches his work during the cutting through a lens of from 1 to 2 inches focus, which is mounted in an adjustable stand directly over the tool. The work is brushed from time to time to allow of its being seen distinctly; but the engraver depends very much on the sense of feeling for placing the work in the proper position with respect to the tool, and upon that of hearing for judging of the progress of the tool. He occasionally takes a proof of his work in blue modelling clay, or in a black wax made by mixing fine charcoal powder with bees'-wax.

It is of great importance that the artist should have his hands perfectly steady, and placed so as to be moved about in all directions with freedom. For this purpose, it is usual for him to rest the palm of the left-hand on the cap of the engine, Fig. 1944, while the forefinger and thumb embrace the revolving tool,

(1) Holtzapffel, "Mechanical Manipulation," vol. iii. The valuable chapter on "Gem and Glass Engraving," describes, for the most part, the practice of Mr. W. Warner in seal-engraving, and of Mr. Henry Weigall in gem-engraving. In Rees's Cyclopædia is a very interesting article on Gems. A treatise on "The Ancient Method of Engraving on Precious Stones compared with the Modern," by L. Natter, Engraver on Gems, was published, in French and in English, in 1754. It appears, from this treatise, that the methods of engraving in use among the ancients closely resembled those of the modern engravers.

and grasp the upper end of the stick on which the stone is mounted. The thumb and forefinger of the right-hand grasp the stick just below those of the left, and the right elbow is supported on a small cushion. A different form of engine would require a different position.

When the engraving is finished, polish is restored to the flat surface of the stone by means of rotten-stone and water applied on a pewter lap. The engraved surfaces of seals are not usually polished; but those of gems are polished most carefully with copper tools charged with very fine diamond powder. The copper being softer than the iron, the diamond powder becomes more deeply imbedded in the surface of the tools, and thus produces a smoother surface. Box-wood tools, with still finer diamond powder, are used after the copper tools; and then the copper tools charged with rottenstone and water.

Cameo-cutting, or the engraving of *gems in relief*, is a similar operation to seal-engraving, or the engraving of gems in intaglio. The stones selected for the purpose are those varieties of agate called *onyxes*[1] [see AGATE] which consist of two layers of different colours, such as the black and white of the agate, and the red and white layers of the carnelian. The design is generally engraved in the white layer, the dark layer forming the background. The stone is prepared by the lapidary, and the artist arranges his design according to the capabilities of the stone. He makes a drawing in paper on an enlarged scale, and a model in wax of the exact size, and the latter is carefully compared with the stone, and such alterations made as the markings on the stone seem to require. The outline is then sketched on the surface, and is cut in with a knife-edged tool *b*, Fig. 1945. The general contour of the figure is next formed, and then the details, the wax model serving as a guide. The surface of the background is flattened by the broad flat surface of such a tool as *d*, Fig. 1945, and small irregularities are removed from the rounded surfaces of the figure with the convex edge of a revolving tool called a *spade:* it is a piece of soft iron, 3 or 4 inches long, the end of which is filed to an angle of 45°, and charged with diamond powder: it is held in the fingers like a pencil, and rubbed on the work with short strokes. The last delicate touches are executed with very small tools, and the cameo is smoothed and polished as described for the best works in intaglio. *Shell-cameos* are described under SHELL.

Engraving on glass resembles seal-engraving in all its essential features; but the designs on glass being larger than those engraved on gems, the tools are larger: the material also being softer, a paste of fine flour, emery, and oil, is used instead of diamond paste.

SEALING-WAX. Before the invention of this substance for securing letters, a kind of bitumen was used for the purpose, and called *terra sigillaris:* it was, according to Beckmann, brought from Asia by the Romans, but was first known among the Egyptians. Pipe-clay was also used for seals, as was also a cement of pitch, wax, plaster, and fat. But there is no evidence of the use of common sealing-wax of earlier date than the sixteenth century. The first recorded letter sealed with it is dated London, August 3, 1554: it is addressed to the Rheingrave Philip Francis von Daun, from his agent in England, Gerhard Hermann. The wax used in sealing this letter is of a dark red colour, very shining, and the impress bears the initials of the writer. The next known seal is on a letter written in 1561 to the Council of Gorlitz, at Breslau: it is sealed in 3 places with beautiful red wax. There are two letters, dated 1563, from Count Louis of Nassau to the Landgrave William IV.: one is sealed with red wax and the other with black. In the records of Plessenburg is an old "expense-book" of 1616, by which it appears that *Spanish* wax, and other materials for writing, were ordered from a manufacturer of sealing-wax at Nuremberg for the personal use of Christian margrave of Brandenburg. It has been supposed, from the term applied to it, that sealing-wax was invented in Spain, but, as Beckmann remarks, "the expression *Spanish-wax* is of little more import than the words *Spanish-green*, *Spanish-flies*, *Spanish-grass*, *Spanish-reed*, and several others, as it was formerly customary to give to all new things, particularly those which excited wonder, the appellation of *Spanish;* and in the like manner, many foreign or new articles have been called *Turkish*, such as *Turkish-wheat*, *Turkish-paper*, &c." According to the same authority, the first printed notice of sealing-wax occurs in the work of Garcia ab Orto, "Aromatum et Simplicium," &c., Antverpiæ, 1574, where the author remarks that strips of *lac* were used for sealing letters. The oldest printed receipt for making sealing-wax occurs in a work by Zimmerman, citizen of Augsburg, 1579. The following is a translation:—"To make hard sealing-wax, called *Spanish-wax*, with which, if letters be sealed, they cannot be opened without breaking the seal:—Take beautiful clear resin, the whitest you can procure, and melt it over a slow coal fire. When it is properly melted, take it from the fire, and for every pound of resin add 2 ounces of vermilion, pounded very fine, stirring it about. Then let the whole cool, or pour it into cold water. Thus you will have beautiful red sealing-wax. If you are desirous of having black wax, add lamp-black to it. With smalt or azure you may have it blue; with white-lead, white; and with orpiment, yellow."

The French also put in a claim to the invention. It is stated that one Francis Rousseau, having, at the end of the reign of Louis XIII., lost all his property

(1) According to Mr. H. Weigall, "all the stones in different coloured layers employed for cameos, are known to practical men by the general name of *onyxes*." The word *onyx* is stated under AGATE to have been applied on account of some resemblance in the stone to the markings of the human *nail*, or to the pink and white colours observable thereon. In many cases, however, there is no such resemblance, at least to the eye of the mineralogist; but Mr. Weigall suggests "that there was an original propriety in the name, and that it most probably arose from the practice of the ancients in staining their nails; for if the stain were only applied at distant intervals of time, the lower portion of the nail would grow between the applications, and present a band of white at the bottom of the coloured nail, and thus render it a fair type of the onyx stone."

in a fire, in order to maintain his family prepared sealing-wax from shell-lac, as he had seen it manufactured in India. Sealing-wax was common in Portugal about the year 1560, and is supposed to have been introduced into that country from India. In the Portuguese Court of the Great Exhibition some sealing-wax was exhibited closely resembling that of Indian manufacture.

The manufacture of sealing-wax was long monopolized by the Dutch, as is evidenced by the legend, "Brand well en vast houd," (Burn well and hold fast,) and this stamp was long adopted by English and other makers; but as it came at length to be placed on wax of all qualities, good and bad, it fell into disrepute, and the name of the manufacturer was preferred. The term *Dutch-wax* now refers to an inferior description of the article.

The term *wax* applied to this article is a misnomer. No wax is used in its manufacture, but *resin*, which is essentially different in its properties. The large seals on public documents are, however, really made of bees'-wax,[1] and it was natural, on the introduction of the resinous compound for sealing letters, to apply the term wax to it; especially as the chemical distinctions between such substances as resin and wax could not at the time have been very well understood. The best kind of resin for making sealing-wax is *Shell-lac*. [See Lac.]

The best red sealing-wax is made by melting 4 lbs. of light-coloured or bleached shell-lac with 1 lb. of Venice turpentine and 3 lbs. of Chinese vermilion. The ingredients must be stirred well together, and when the mixture is nearly set a quantity sufficient for 6 sticks is weighed out. The sticks are made on a raised marble slab, heated by a chafing-dish placed underneath. The wax is rolled on this slab with the hands into a roll of nearly the length of 6 sticks, after which the proper length and thickness are given by rolling it with a square piece of hard wood. The stick is then taken by another workman, who rolls it upon a cold marble slab with a marble roller until it is cold. The stick is polished by holding it between two charcoal fires, placed opposite each other, a short distance apart: the melting of the wax produces a smooth surface. Five deep indentations are made in the wax, so as to divide it into 6 equal parts. A third workman breaks the long sticks into the short lengths, and finishes the top by holding it in the flame of a lamp, and impressing the maker's seal upon the end.

Oval, grooved, channelled, and other ornamental forms, are made by pouring the fluid wax into steel moulds. *Golden* sealing-wax is made by using powdered yellow mica, or cat-gold, instead of vermilion. Blue wax is made by colouring the resin with smalt or verditer: ivory-black is used for black wax; massicot, or turbith mineral, for yellow, and so on. Wax may be rendered fragrant by adding to the other ingredients ambergris, musk, oil of rhodium or oil of benjamin, &c. The addition of camphor improves the burning, but renders it unfit for use in warm climates.

An inferior wax is made by substituting common resin for the lac, red lead for the vermilion, and common turpentine for that of Venice. Sticks of this wax are made to appear like wax of good quality, by softening them between two fires, and then rolling them in powdered wax of a better quality: the sticks are again softened to melt this false coating and produce a polish. For inferior black wax, lamp-black is used instead of ivory-black.

Although in sealing letters the most expeditious plan is to ignite the wax, this does not give the best impressions of the seal. With the finest red wax good impressions can be made at a temperature of 140°. The beautiful proof impressions of seals made by the seal-engravers are taken by first brushing the seal with a soft brush, warming it by moving it round the flame of a candle, until just hot enough to be borne without pain by the naked hand; then applying to the seal a thin layer of clean tallow, by means of a small brush, and coating this with a thin layer of vermilion, applied by means of a camel's-hair pencil. The sealing-wax is prepared by softening it at a short distance from the candle until a sufficient quantity can be detached for the purpose; but the wax must not be ignited nor blackened. The softened wax is placed in a small heap upon a piece of stout paper, and gently warmed, by holding it above the flame, high enough not to blacken the paper. The wax is stirred with a small stick for the purpose of excluding air-bubbles and working it up into a conical mass. When the surface of the wax is bright and quiescent, the seal, which should be of about the same temperature as the wax, is quickly dabbed upon the wax with a firm perpendicular stroke and moderate pressure. By thus suddenly dabbing the seal down, the wax is forced into the minute crevices of the seal more effectually than by a long continued pressure.

SEASONING. See Timber.

SEA-WATER. See Sodium—Waters mineral.

SEBACIC ACID,[2] a constant product of the destructive distillation of oleic acid, oleine, and all fatty substances containing them. It is extracted by boiling the distilled matter with water: it forms small pearly crystals, and has a faint acid taste. It is composed of $C_{10}H_8O_3$.

SEGGAR. See Pottery and Porcelain, Sec. VII.

SELENIUM, (Se 40), a rare substance discovered by Berzelius, in 1817, while examining certain substances in the sulphuric acid manufactured at Gripsholm, in Sweden. It resembles sulphur in its chemical relations, and in some few places occurs associated with that mineral, or taking its place in certain metallic combinations, as in the seleniuret of lead of Clausthal in the Hartz. Selenium is a brittle solid, of a reddish-brown colour, and with an imper-

(1) The Great Seal of England is made up according to a recipe in the Lord Chancellor's Office. It is said to be prepared by melting block-white wax in about 1-fourth of its weight of Venice turpentine. The wax of the Great Seal and Privy Seal of Scotland is made from resin and bees'-wax coloured with vermilion. The Exchequer Seal is green. Seals made of soft wax are not permanent, and the impression is dull.

(2) *Sebaceus* (Latin), a tallow candle.

fect metallic lustre. Its sp. gr. is 4·2 to 4·3. It fuses at about 212°, and boils at 650°. When heated in the air its odour resembles that of decaying horse-radish. It is insoluble in water. There are 3 oxides of selenium, 2 of which, selenious and selenic acids, correspond with sulphurous and sulphuric acids. The seleniates bear a close analogy to the sulphates.

SELZER WATER. See WATERS MINERAL.

SENNA. The dried leaves of certain annual leguminous plants of the genus *Cassia*, natives of Arabia and Egypt. Their useful medicinal properties are well known. The leaves of plants belonging to other genera are mixed with senna as adulterants. The great supply of senna to Europe is obtained from Alexandria: Calcutta and Bombay also export a large amount under the name of East India senna, but which is originally brought from Arabia.

SEPIA, a valuable pigment, used by artists, and named after the molluscous animal (*Sepia*) which produces it. The common cuttle-fish, *Sepia officinalis*, is about a foot in length, of an oval form, and jelly-like substance, covered by a coarse skin. The body is supported by an internal plate or shell, hard in texture, and white in colour, but composed on one side of very delicate layers of shelly matter, which rise perpendicularly in laminæ, of beautiful construction, well worthy microscopic examination. This is the ordinary cuttle used as pounce and as a polishing powder for soft metals. The cuttle-fish has 8 arms and 2 long feet, all situated near the head, (hence these creatures are called *Cephalopods*,) and furnished with suckers, which enable it to hold fast the fish on which it preys. It has also a parrot-like beak, which makes it a formidable enemy. As a means of defence when attacked, the cuttle-fish is provided with a bladder-shaped sac of fluid resembling ink, which it can discharge in a moment, and which darkens the water round it so completely as to favour its escape. The ink obtained from this, and from two other species of cuttle-fish, forms when dried the well-known *sepia*. The whole family of this mollusk secrete an inky fluid; but that of *S. officinalis*, *S. ioligo*, and *S. tunicata*, is most valued. The sac containing it is extracted, and the ink dried rapidly, or it becomes putrid. Sepia consists of carbon in a minutely divided form, albumen, gelatine, and phosphate of lime. Caustic alkalis dissolve and turn it brown, but as the alkalis become carbonated the sepia falls down. The dried sepia is prepared for the use of the artist by first triturating it with a little caustic lye, then adding more lye, and boiling half an hour. The liquid is then filtered, the alkali is saturated with an acid, the precipitate deposited, washed with water, and finally dried at a gentle heat. Sepia is of a good brown colour, and very fine in grain. It is a remarkable fact, that sepia has remained unchanged in its properties for countless centuries. Among the petrified remains of the ancient world, sepia was found in the bodies of extinct cephalopods. In the lias of Lyme Regis ink-bags were found in a fossil state, still distended as when they formed part of the organization of living bodies. Dr. Buckland, who states this fact in his *Bridgewater Treatise*, says—"So completely are the character and qualities of this ink retained in these specimens, that when, in 1826, I submitted a portion of it to my friend Sir Francis Chantrey, requesting him to try its power as a pigment, and he had prepared a drawing with a triturated portion of this fossil substance; the drawing was shown to a celebrated painter without any information as to its origin, and he immediately pronounced it to be tinted with sepia of excellent quality, and begged to be informed by what colourman it was prepared."

SEPTARIA, lenticular concretions of clay ironstone intersected by veins of calc-spar. When calcined and ground to powder they form a good hydraulic cement. See MORTARS and CEMENTS.

SERPENTINE, also called *Ophite*, includes several varieties of hydrous silicates, of magnesia with iron, manganese or chrome, and sometimes alumina. Precious serpentine is a beautiful marble, forming, when mixed with limestone, *verd antique*. Slabs of serpentine are sometimes used for the floors of bakers' ovens.

SEWER,[1] a subterranean passage formed for the drainage of a town. The ancient Romans seem to have been far in advance of the moderns in respect of sanatory regulations, for they took especial pains to secure those two great necessaries of urban life, an abundant supply of water and efficient drainage. Covered drains, or sewers of great magnitude and of solid construction, still exist under the streets of some ancient Roman cities, and the cloacæ or sewers of Rome are of such vast size, that some writers have supposed them to be the remains of a city more ancient than that of Rome. In modern times the sewers of London are unrivalled for extent and excellent construction; and although they are not equal to the wants of a vast and constantly increasing population, yet, when we come to consider fairly the difficulties of the case, it may excite surprise that so much has been done, and so well, within a comparatively short period. It is much more easy to point out defects in the existing system than to suggest a remedy that shall work as well in practice as it reads well on paper. For instance, we are told, and the fact is undoubted, that the drainage of a large town, which is poured to waste into the river which passes through it, poisoning the waters and rendering the air pestilential, would, if properly distributed over its banks, bestow upon them unbounded fertility. But when we consider that the excrementitious matters produced by each individual may amount to an annual quantity equal to one ton in weight, and that the other matters included under house sewage and street drainage, may amount to a similar quantity, we have thus a total equal to two tons per annum for every individual of the population. Taking the population of London at two millions and a half we thus have five million tons of drainage to dispose of every year, and how to get rid of this without contaminating

(1) A sewer being a place whence water *issues* or *sues*, we thus get the word *suera* or *sewer*. The word is sometimes pronounced *shore*.

the Thames, or polluting the air of London; how to extend its fertilizing presence over the arable lands and the pastures of the surrounding country, we confess ourselves unable to state, or even to admit that the plans submitted for the purpose are within the means of the metropolis.

It was certainly an act of sad necessity which led men to convert streams of pure water into channels of filth and refuse. Some of the old writers speak of the natural water-courses of old London as being "choice fountains of water, sweet, wholesome, and clear." Under this designation come the rills which descended from the high ground about Hampstead, and by the union of their tributary streams formed the *Fleet* river. It appears, however, that so early as the year 1290, the monks of White Friars complained to the king and parliament that the putrid exhalations arising from the stream were so powerful as to overcome all the frankincense burnt at their altars, and had even occasioned the deaths of many of the brethren. Attempts were made to cleanse the Fleet river and to restore it to its former condition as a navigable stream; but the necessity of providing for the wants of the population increasing on its banks defeated the attempts, and in course of time the Fleet dyke or ditch became a great arched sewer, receiving the contents of innumerable subsidiary sewers and drains, and discharging its filthy load into the Thames.

The Fleet is only one out of many of the main-sewers of the metropolis,[1] all pouring into the Thames, and all having an increased duty to perform as the suburban dwellings increase in number. There is no denying that this system of drainage is an evil, but how vastly greater is the evil to those districts which have no drainage, or only a very imperfect drainage, will appear from the high testimony of Dr. Southwood Smith, who, in his evidence before the Parliamentary Committee on the Health of Towns (1840) said:—"If you were to take a map and mark out the districts which are the constant seats of fever in London, as ascertained by the records of the Fever Hospital, and at the same time compare it with a map of the sewers of the metropolis, you would be able to mark out invariably, and with absolute certainty, where the sewers are, and where they are not, by observing where fever exists; so that we can always tell where the Commissioners of Sewers have not been at work by the track of a fever."

(1) Some of the principal sewers of the metropolis are, on the *North*:—1, the Counters' Creek; 2, the Ranelagh Sewer; 3, the King's Scholars' Pond Sewer; 4, Scotland Yard; 5, the River Fleet; 6, Finsbury and Shoreditch Sewer; 7, Limehouse Creek, or the Black Ditch; 8, the River Lea. These sewers drain collectively 18,640 acres of land. The high lands comprise 13,700 acres, but the remaining 4,940 acres are only a few feet above, and in some cases are below the Thames high-water-marks.

The *drainage* tributaries *South* of the Thames are:—1, the River Wandle; 2, the Rivulet between Wandsworth and Clapham Common; 3, the Effra Brook at Vauxhall Bridge; 4, the Battle Bridge Sewer below London Bridge; 5, the Duffield Sewer; 6, the Earl's Brook; 7, the Ravensbourne. These drain 15,000 acres of land. The high lands, comprising 6,790 acres, sometimes flood the low marshy district of 6,700 acres lying between them and the Thames.

It has been somewhat unfortunate that the different districts into which the metropolis is divided, as respects its sewers, should have been managed by distinct sets of commissioners. The consequence has been that the sewers of one district have been enlarged without any reference to the capacity of sewers at a lower level. Thus the sewers of the Holborn and Finsbury divisions have no outfalls of their own into the Thames, but communicate therewith through those of the City of London Commission. When the sewers of the two first-named commissions were improved and enlarged, they occasionally poured so large a quantity of water into the City of London sewers, that the latter were unable to discharge it, so that during heavy falls of rain the water was forced up the drains into the neighbouring houses. The city was thus compelled, at great expense, to enlarge its sewers, whereas, if the respective commissioners had concerted their measures together, the enlargements and improvements would have been carried on simultaneously, and the inconvenience avoided. Some idea may be formed of the quantity of drainage which has to be discharged by these vast subterranean works by the following brief statement of some of their dimensions:—The Irongate sewer, which was formerly the City ditch, varies in height from 6 feet 6 inches to 11 feet, and in width from 3 feet to 4 feet. The Moorfields sewer is 8 feet 6 inches by 7 feet, and at the mouth 10 feet by 8 feet: at the north end of the Pavement this sewer is 27 feet below the surface. The Fleet ditch, which drains from the south-west of Highgate to the Thames, is partly formed in two distinct sewers which run on each side of Farringdon-street; they are from 12 feet to 14 feet high, and each is 6 feet 6 inches wide; but they are liable to be flooded by the rush of waters from the north, and a single storm will, in a few minutes, raise the water 5 feet in height in both sewers. The Fleet sewer conveys the drainage of about 4,444 square acres of surface in the Holborn and Finsbury and the City of London divisions, and it is calculated that this surface discharges annually into the sewer about 100,000 cubic yards of matter, held in mechanical suspension, and carried to the Thames by the force of the water which flows through the sewer. The water is about 100 times the bulk of the matters suspended in them: hence the Fleet sewer discharges from the above limited surface about 10,000,000 cubic yards of sewage into the Thames annually. The total work of the sewer is however much greater than this. A sewer carried up to Holloway in this division for a length of nearly 3 miles,[2] passes under Canonbury at Islington at a depth of 68 feet from the surface; the

(2) Referring to this sewer, the Surveyor of the City Division remarks:—"The sewer from Moorfields to Holloway appears to measure upon the map about *three* lineal miles. In process of time, and as buildings increase, it may throw out branches in all directions, and the three miles may become *thirty;* not only all the atmospheric waters which may, upon an average, fall within the valley south-eastward of Highgate, or at least a large portion of them, but all the artificial supplies which the wants of its yet future inhabitants, as well as of those intermediate, between Islington and Moorfields, may require, will have to be carried off by the City Sewers."

drainage of the houses in that part being provided for by a subsidiary sewer.

Another defect arising from want of unity of plan in the construction of the metropolitan sewers, is the want of a uniform rate of declivity sufficient to discharge the sewage. Indeed many of the sewers are laid perfectly level, and hence act as cess-pits instead of channels of discharge. To remedy the evils of insufficient declivity the process of *flushing* has been adopted in the sewers; that is, the water is allowed to accumulate for a time by means of gates or dams, and is then suddenly let loose so as to act like a powerful current in sweeping all the loose matter before it. Another consequence of the low level of many of the London sewers is that their outfalls into the river are so low, that their contents are delivered at or a little above, low-water level. The consequence is that the decomposing matters are left upon the banks of the river to stagnate and to corrupt the air; and the next tide extends the pollution by carrying them higher up the stream, and thoroughly mixing them with the waters. If an adequate fall could be procured the sewers might be made to discharge into the river at or near the high-water level, in which case the sewage would be conveyed away from the higher to the lower districts. In some cases the water of the rising tide enters the sewers and prevents for the time the discharge of sewage, so that the gaseous products of the decomposing matters in the sewer are driven back towards the town. In other cases the tide is prevented from entering the sewers by closing their lower ends with valves or heavy flaps, and men, named *flap-keepers*, are appointed, whose duty it is to open the flaps at proper times, so as to allow the sewage to escape at low water. In the Pimlico district, adjoining the palace, the fall for the last 5,500 feet is only 5 feet, and the outlet is furnished with flood gates, which are kept closed for 6 hours, during the rising of the tide. Sewers also not only require to be flushed but also to be cleansed by hand, the foul matter being raised to the surface in buckets and carted away. In the Westminister division the outfalls to the river vary from 10 to 15 feet below the level of high-water mark, that is, about 5 feet above low-water mark. The cost of cleansing these sewers by hand, thus required by the deficiency of fall, amounted on an average of 7 years to about 1,550*l.* a-year, and the deposit is sometimes found to be so hard that it requires the use of the pickaxe to dislodge it. Some of the main sewers in this division have a fall of only ½ inch in 100 feet.

The forms of sewers vary in different districts. In the Westminster district they are built of the form represented in the transverse section, Fig. 1946, of which the height varies from 5 feet to 5 feet 6 inches, and the width from 2 feet 6 inches to 3 feet. The regulations for building sewers issued by the Commissioners require that the bricks used be "good, square, hard, sound, and well-burnt stock bricks, and be properly laid in well compounded mortar, made of one part of good strong stone lime, and 2 parts of clean river sand; the workmanship to be of the best description, the bricks of each arch to be well bonded, and the bricks of the arch at the bottom of the sewer to be laid close at the top edge, and to an even curvature on the upper surface, bedded in mortar and grouted." When Roman cement is used in the works "it shall be of the best quality, and shall not be mixed with more than one half of clean river sand." The form of sewer represented in Fig. 1946 is not calculated to give the greatest strength: indeed, in some cases, the sides have given way to the pressure of the earth behind them.

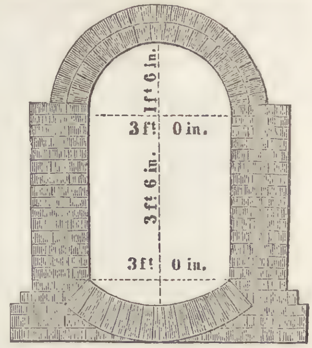


Fig. 1946.

In the Holborn and Finsbury commission the oval form, Figs. 1947, 1948, is preferred. The part where the joints are marked in the engravings is directed to be worked in blocks

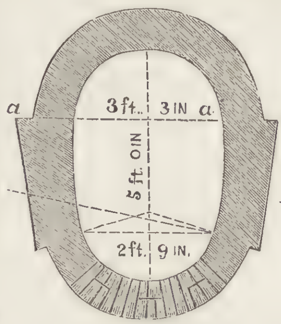


Fig. 1947.

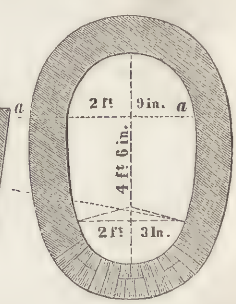


Fig. 1948.

with cement. It is required by this commission that every main or leading sewer, "which may receive the sewage from streets and places containing more than 200 houses, shall be of an oval form, 5 feet in height and 3 feet in width in the clear: the invert thereof to be worked one brick in substance, and the springing walls thereof to be worked one brick and a half in substance, and bonded, and the crown thereof one brick in substance, in two separate half bricks," as in the transverse section, Fig. 1947. All branch sewers which may receive the sewage from streets containing less than 200 houses, are to be 4 feet 6 inches in height, and 2 feet 6 inches in width in the clear, the whole being worked one brick in substance, the bottom and springing walls being bonded, and the crown worked in 2 separate half bricks, as in the section, Fig. 1948, which is called the *second size.* The sides of these sewers form curves of large radius, struck from centres on the line *a a:* the radius for the larger size being about 13 feet, and that for the smaller size in proportion. The difference in expense between sewers of the sections, Figs. 1946, 1948, has been estimated at 1,600*l.* per mile in favour of the egg-shaped or oviform section. The inverted arch which forms the

bottom of a sewer adds greatly to its strength, and assists the motion and force of the current. In the Surrey division the soil is in some places so bad from the pressure of quicksands that cast-iron bottoms have been used.

The inclination and depth of sewers must be regulated according to circumstances. The Holborn and Finsbury regulations require that "the inclination be not less than $\frac{1}{4}$ inch to every 10 feet in length, and as much more as circumstances will admit in those portions that are in a straight line, and double that fall in portions that are curved." It is stated in the regulations of the Westminster Commission (1836) that the currents required for sewers in all cases is $1\frac{1}{4}$ inch to every length of 10 feet; but later regulations order "that the current of all sewers to be built, be regulated by the commissioners according to surface required to be drained," without stating any particular inclination. It is, as already observed, frequently a matter of difficulty to obtain sufficient inclination in a sewer, and yet to make it deep enough to drain the basement story of the neighbouring houses, some parts of the metrŏpolis being below the level of high water. In crowded districts also, where deep and capacious sewers are most required, it has been found necessary during their construction to shore up the houses with massive timber framings, to prevent them from falling, and in some cases the danger to the houses has prevented the formation of any sewer at all. Such houses are, therefore, furnished with cesspools, which are permanent sources of offensive and unwholesome effluvia, and unless constructed with good substantial brickwork, the liquid contents will saturate the soil, and finally appear at the surface, or escape through some defective foundation, and poison the basement of an adjoining building. As the cesspools become filled they must be emptied. This was formerly done by taking out the contents in buckets, and filling them into a night-cart, a slow, disgusting, and expensive operation. It is now done quickly and cheaply by means of a pumping apparatus, consisting of a close tank mounted upon 2 or 4 wheels, with a hose fitted to an aperture in it, and an air-pump attached: the hose is of such a length that it may be laid through the passage, &c., of a house, and dipped into the cesspool, while the other end is attached to the tank at the street door, into which the contents of the cesspool are rapidly transferred by a labourer at the pump. The contents of one large cesspool, equal to 24 loads of soil, can be pumped out in about 4 hours, at a cost of 24*s*. Under the old system 3 nights would have been occupied in emptying such a cesspool, and the cost would have been at least 24*l*.

Sewers receive the drainage of houses by means of small channels or *drains*, usually of circular form, and from 6 to 9 or 15 inches in diameter, for which purpose the lowest part of the building should be at least 4 feet above the level of the sewer, measuring to the bottom of the side wall or commencement of the invert. If this precaution be not taken the house will be liable to be flooded from the sewer when the latter is unusually full.[1] The Westminster commissioners require that the bottoms of private drains shall be 12 inches above the bottom of the sewer; and they recommend that such drains have a fall of at least $\frac{1}{4}$-inch in a foot. If the length of the drain be 60 feet, the fall amounts to 15 inches, which, added to 13 inches for the height of the drain and brick arch over it, 8 inches for the depth of ground and paving over the upper end of the drain, and 12 inches between its lower end and the bottom of the sewer, gives the total fall of 4 feet. The brick rings at the junctions of private drains with the sewers, are usually made by the commissioners at the cost of the proprietor of the drain. The various metropolitan commissions are however by no means uniform in their regulations for the construction either of sewers or of drains.

Glazed stoneware pipes are excellent substitutes for brickwork in the smaller drains. They are more quickly laid than the others can be built, and they present a much better surface for the rapid flow of the sewage. They are constructed in various forms of bends and junction pieces, and from the comparative thinness of these pipes a much larger capacity is obtained with a given quantity of excavation for laying them, than brickwork sewers, which even for the smallest diameter cannot be less than half a brick, or $4\frac{1}{2}$ inches in thickness. Each pipe has a socket at one end for receiving the plain end of the adjoining pipe.

In order to obtain entrance to the sewers it was formerly the practice to construct man-holes at every intersection of the sewers. These holes were oblong shafts of brickwork, carried up to within 18 inches of the surface of the road, and covered with cast-iron plates, over which the roadway was formed. Hence, in order to obtain access to the sewer, it was necessary to break up the road. This inconvenience led to the formation of side entrances or passages, extending from the side of the sewer by a short passage or tunnel to a square or rectangular shaft, opening into the foot pavement, where it is closed by a trap-door consisting of pieces of flag-stone mounted in an iron frame. On raising this cover it is held open by a self-acting catch, and an iron grating rises in its place, and while admitting light and air to the passage prevents the passenger from falling in. The shaft is provided with hand-irons built into the wall, by which a man can readily descend and ascend.

The surface drainage of the streets is conducted into the sewers by means of gully-holes and shoots, Fig. 1949. In this figure is shown a very simple plan for preventing the effluvia of the sewers from escaping into the streets. *g* is the grating, imbedded as usual in the pavement of the gutter. *d* is a passage leading to the sewer, and the vertical shaft is carried down below this passage, the bottom of the shaft being formed into a receptacle for the solid matter or mud which enters with the water: this can be cleaned out about once a month or oftener as

(1) Such an accident sometimes happens during the artificial scouring or flushing of the sewers: the sewage is forced up into the streets and houses from some of the lower sewers which become overcharged with the flushing water.

required. The curtain wall or dipping valve, at *c*, extends a little below the level of the entrance to the sewer, so that when the well is filled to the level of

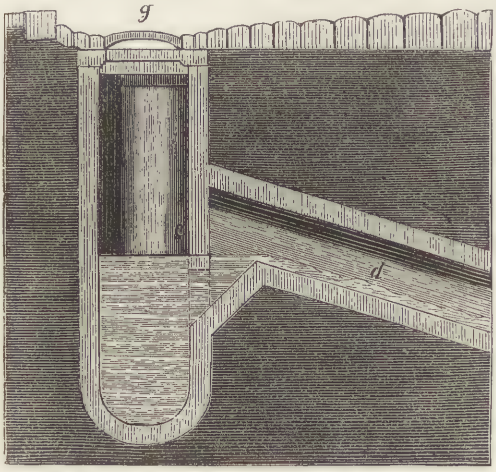


Fig. 1949.

the inclined passage it allows water to flow freely into the sewer, but prevents air from escaping from the sewer into the gully-hole.

The necessity for some contrivance of this sort, if the foul air of the sewers cannot be otherwise got rid of, will be evident from the statement made by Mr. Fuller, a medical man, to the parliamentary committee of 1834, viz. that of all the cases of severe typhus that he had seen, 8-tenths were in houses either untrapped from the sewers, or which being trapped were situated opposite to gully-holes; and cases were mentioned in which servants sleeping in the lower parts of such houses were invariably attacked with typhus. It is also stated that butchers' shops cannot exist opposite or near to untrapped gully-holes, in consequence of the injurious action of the effluvia on the meat.

The trapping of the gully-holes has the effect of confining in the sewers the gases arising from the fermentation of the putrid matters of the sewage; and as some of the compounds of hydrogen are thus evolved in large quantities, these gases form, with the common atmospheric air of the sewers, an explosive mixture, thus exposing the lives of the men whose duty it is to enter the sewers with lamps. Hence it is necessary to provide some means for the escape of the gases from the sewers, and for this purpose the commissioners of some of the districts require the gully-holes to be kept open, not allowing them to be trapped; but even these numerous vents are not sufficient for the escape of the putrid gases. It has therefore been proposed by Mr. Fuller to burn out the foul air from the sewers; for which purpose he proposes to erect, as near as convenient to the highest point of every main sewer, a large furnace with a tall chimney, so connected with the sewer that the fire shall be supplied with air from the sewer only. The lower end of the sewer is to be closed with a trap that will allow water, but not air, to pass; so that air may only enter at the gully-holes, of which a sufficient number must be left open to supply the furnace with air, the remainder being trapped. By thus maintaining a constant downward draught in the gully-holes, and passing the air of the sewer through the fire, it was supposed that the poisonous gases would be burnt, and by discharging the products of combustion at a great elevation, the nuisance of the gully-holes might be got rid of. It has also been proposed that the large fires of some manufacturing establishments might be usefully applied to the ventilation of sewers.

The entrances to private drains are usually secured by a *stink-trap*, a simple and convenient form of which is represented under ABATTOIR, Fig. 7. These traps are constructed in a variety of forms, but they depend for their action upon the formation of what the chemist calls a *water-lute*, the principle of which is shown in Fig. 7, and also in Fig. 1949.

Our space will not allow us to enter into the details of the numerous schemes which have been proposed for providing for the sewage of the metropolis without discharging it into the Thames. Mr. John Martin, the artist, proposed, so long since as the year 1828, that the sewage should be discharged into spacious reservoirs, to be formed near the banks of the Thames, in which reservoirs the solid matter might subside so as to become useful as manure; the watery part was then to be discharged into the river. Another plan is to conduct the sewage several miles below London before it is allowed to enter the river. A few years ago the "Metropolitan Sewage Manure Company" was formed for the purpose of "conveying the sewage water of London by means of a system of pumping engines and pipes, analogous to that of the great water companies, and thus distributing the fertilizing fluid over the land in such manner and proportions as may be best adapted to the various kinds of field and garden cultivation." Mr. Wicksteed has proposed to carry away the entire sewage of the metropolis in a tunnel of from 8 to 12 feet in diameter, and at a depth of from 40 to 80 feet beneath the surface of the streets. The sewage was to be discharged into a large reservoir, and works to be constructed in an angle between the western banks of Barking Creek and the northern banks of the Thames. "The sewer water was to be raised by steam-engines from the receiving reservoir into other reservoirs, sufficiently elevated to permit the solid matters to be deposited at a level above the Trinity high-water mark. From these reservoirs the solid matter was to be periodically removed, dried by artificial means, and then compressed and packed for transmission by land or water. The liquid matter was to be discharged as worthless at all states of the tide." Another plan, by Mr. Higgs, patented in April 1846, embraced the chemical treatment of the sewage. It was to be received into reservoirs with suitable buildings over them, in which the gases evolved are to be collected, condensed, and combined with chemical agents, and the salts thus formed were to be crystallized on an arrangement of spars or bars. The solid matters were to be dried and cut into suitable shapes for transport as manure. For

further details on this subject we refer to the Report of the Committee appointed in 1846 to consider plans for the application of the sewage of the metropolis to agricultural purposes.[1]

SHAFTS or AXLES. See COUPLINGS—GEARINGS—WHEEL.

SHAGREEN, a dried animal skin, differing from leather in not being tanned or tawed. It bears some resemblance to parchment, but the grain or hair side is granulated or covered with small round rough specks. It is an oriental manufacture, and the method of preparing it was long kept secret. It is said to be prepared from the skins of horses, wild asses and camels, those portions being preferred which cover the chine. The fillets of skin are steeped in water until the hair is sufficiently loosened to be scraped off; the skins are then stretched upon a board, and are unhaired and fleshed with a knife. Each fillet is then stretched in a frame, as in the preparation of parchment, [See PARCHMENT, Fig. 1589,] and is moistened from time to time and gradually distended. While still moist, the grain or hair side is sprinkled over with the seeds of a kind of *Chenapodium;* they are hard, of a shining black colour, and about the size of poppy seed. These seeds are forced into the surface of the skin by the pressure of the feet, or by means of a simple press, a piece of felt or thick stuff being laid over the seeds. In this state the skin is left to dry in the shade, and when the seeds are shaken out by beating the skin, the surface of the latter is pitted with small hollows corresponding with the forms of the seeds. The skin is now stretched on an inclined plane, by attaching its upper end to hooks and fastening weights to its lower end, and it is thinned off with a half-moon knife, Fig 1590, care being taken not to cut so far as the bottom of the little pits occasioned by the seeds. On macerating the skins in water they swell, and the pits become prominent over the shaven surface. The process is completed by steeping the strips in a warm solution of soda; salt brine is then used, and the skins are ready for the dyer.

SHALE, a term applied to any argillaceous deposit naturally divisible into laminæ parallel to the plane of deposition. Thus there are *sandy*, *calcareous*, purely *argillaceous*, and *carbonaceous* shales; there is also a *black* and a *brown bituminous* shale; the latter, met with at Kimmeridge in Hampshire, is called *Kimmeridge coal.*

SHAMOY. See LEATHER.

SHAPING MACHING. A machine under this name was introduced by Brunel for shaping the wood in the manufacture of ship's blocks. [See BLOCK, Fig. 153.] The *mortising engine* of the block machinery, Fig. 151, was applied by Mr. Roberts of Manchester to the formation of the key-ways of cast-iron wheels, and also to the paring or planing by short strokes of the sides of small curvilinear pieces of metal, such as cams, short levers, and other pieces which do not admit of being finished in the lathe. The machines thus introduced were first called *key-groove engines*, and afterwards the *slotting* and *paring machine.* Still later another machine for shaping metal pieces and parts of machinery was introduced under the name of the *shaping machine:* it is a modification of the *planing machine:* the tool is attached to the end of a horizontal bar, which is moved to and fro, so as to plane with short transverse strokes a piece of work, fixed on a complex adjusting bed or turntable so as to receive the action of the tool.

SHARPENING. See CUTLERY—HONE.

SHEARS, are cutting edges used in pairs, and on opposite sides of the material to be cut, sheared, or severed. In some cases shears are formed after the manner of pincers and pliers, or as two double-ended levers united at the fulcrum by a pin. Scissors are described under CUTLERY. The largest kind of shears, such as are used for dividing bars of iron, 4, 5, or 6 inches wide, and 1 to 2 inches thick, are described under IRON, Fig. 1241. Shears in which the cutting edges are in two parts not united by a pin, are shown under NAILS, Fig. 1494. See also PAPER, Fig. 1580, &c.

SHEATHING. See SHIP.

SHEET-METAL WORKS. See RAISED WORKS in METAL.

SHEETING PILE. See BRIDGE. Sect. III. Figs. 282, 283.

SHELL. The protective covering of a class of animals widely distributed throughout the earth, the fresh waters, and the ocean. This covering is in most cases exterior, and large enough to enclose the whole body; but in some cases it is interior, and only of sufficient size to protect the heart and lungs. Shell is a secretion from the skin which covers the back of the animal, and which is of a peculiar thickness and fleshy consistence, and is called the *mantle.* This fleshy mantle is very evident on the back of the common grey slug, in which it covers only a portion of the body, and contains in general, within its substance, an internal shell, small, flat, transparent, and oval. The snail affords a familiar instance of an external shell.

Shells are called *univalve* or *bivalve* according as they consist of one part, or of two parts joined together by a hinge. The snail is univalve, the oyster is bivalve. Bivalves are inferior in the scale of existence to univalves, both as it respects powers of motion and organs of sense. The generality of the bivalve shells, including various oysters, mussels, &c., are termed *nacreous* shells, from *nacre*, the French for mother-of-pearl. Their structure and uses in the arts have been already treated of [See MOTHER-OF-PEARL], while the ornamental employment of shells in general, as illustrated in the Great Exhibition, has been noticed in the INTRODUCTORY ESSAY, p. cxxix. It remains therefore to speak of the univalve shells, and their employment in the arts.

Most of the univalve shells are of the character called *porcelanous* from their brittleness, translucence,

(1) Mr. Dempsey, in his Treatise on the Drainage of Towns and Buildings, published in 1849, in Weale's Rudimentary Series, gives the details of an original plan for the drainage of London. Much valuable information respecting Sewers is given in the "Report of the Commissioners of Inquiry into the State of large Towns and populous Districts. 1843."

and the resemblance of their fracture to that of porcelain. But this fracture when examined by the microscope reveals a structure of thick parallel layers, usually of a finely fibrous nature, at right angles to the external surface. Dr. Aikin says that these fibres are often nothing more than the transverse section of thin transparent parallel lamellæ, which when viewed on their broad surfaces often exhibit the usual natural joints of calcareous spar. The soluble part of these shells is carbonate of lime, the particles of which are cemented together with a very minute proportion of animal mucus. The hard and compact nature of such shells, and their generally smooth surface, prevent their being cut by the ordinary tools, which are available for the less hard and frangible nacreous shells: it is therefore necessary to treat them after the manner of the lapidary, [See LAPIDARY WORK,] with emery, rottenstone, and other substances harder than the shells themselves. Such shells generally require rather to be polished than cut, but where it is necessary to divide them in order to exhibit their sections, they are operated upon by means of the slicer with diamond powder. Certain descriptions of these shells are well adapted for cameo-cutting, on account of their substance being made up of differently coloured layers, and also on account of a difference of hardness and texture in the different layers, some approaching more nearly to the nature of nacreous than of porcelanous material. Specimens of cameo-shells, and of the rude but efficient instruments for cutting them, were shown in the Indian collection of the Great Exhibition. The shells were dense, thick, and consisted of three layers of differently coloured shell material. "In the *Cassia rufa* each layer is composed of many very thin plates, in other words is laminated, the laminæ being perpendicular to the plane of the main layer: each lamina consists of a series of elongated prismatic cells, adherent by their long sides. The laminæ of the outer and inner layers are parallel to the lines of growth, while those of the middle layer are at right angles to them."[1] Several varieties of the genus *Strombus*,[2] or conch, supply suitable shells for cameo cutting. The outer layer is nearly colourless, can be operated upon with steel tools, and may be carved into smooth and finished forms. Experience has taught the cameo-cutter to choose the kinds known as the *Bull's Mouth*, the *Black Helmet*, the *Horned Helmet*, and the *Queen Conch*, of which the first two are the best. The art of cameo cutting was confined to Rome for upwards of forty years, and to Italy until the last twenty-six years, at which time an Italian began cutting cameos in Paris, and now upwards of 300 persons are employed in the trade in that city. About thirty years ago, the total annual number of shells used in the trade was about 300: the whole of them were sent from England, and they were worth 30 shillings each in Rome. But so rapid was the progress of the manufacture when it became more widely diffused, that the following numbers were given a few years ago, (1847,) by Mr. Gray, as the consumption of shells in France for this purpose.

Bull's Mouth.........	80,000	average price	1*s*. 8*d*.	value	6,400*l*.
Black Helmet	8,000	—	5*s*. 0*d*.	—	1,800*l*.
Horned Helmet	500	—	2*s*. 6*d*.	—	60*l*.
Queen Conch.........	12,000	—	1*s*. 2½*d*.	—	700*l*.
	100,500	shells.			£8,960

The average value of the large cameos made in Paris, as stated by the same authority, is 6 francs each, giving a sterling value of 32,000*l*., and the value of the small cameos is about 8,000*l*., giving a total value of the cameos produced in Paris, in one year, (1846,) at 40,000*l*.; while at the same time in England, not more than six persons were employed at the trade. The Black Helmet, on account of the advantageous contrast of colour in the layers, produces very effective cameos, the carved figure of the white upper layer being strongly relieved by the dark, almost black ground, supplied by the second layer. The shell is first cut into pieces the size of the required cameos, by means of diamond dust and the slitting mill, or by a blade of iron or steel fed with emery and water. It is then carefully shaped into a square, oval or other shape on the grindstone, and the edges are finished with oilstone. It is next cemented to a block of wood, which serves as a handle to be grasped by the artist while tracing out with a pencil the figure to be cut on the shell. The pencil mark is followed by a sharp point, which scratches the desired outline, and this again by delicate tools of steel wire flattened at the end and hardened, and by files and gravers, for the removal of the superfluous portions of the white enamel. A common darning-needle, fixed in a wooden handle, forms a useful tool in this very minute and delicate species of carving. The careful manipulation necessary in this work can only be acquired by experience, but there are general rules thus sensibly given which the learner would do well to remember:—"As in all other processes of producing form by reduction, the general shape should be first wrought, with care to leave every projection rather in excess, to be gradually reduced as the details and finish of the work are approached. To render the high parts more distinct during the process of carving, it will be found convenient to mark them slightly with a black-lead pencil. Throughout the cutting great caution should be observed, that in removing the white thickness the dark ground is not damaged, as the natural surface of the dark layer is far superior to any that can be given artificially; indeed, should the ground be broken up at one part, it would be requisite from its lamellar structure to remove the entire scale or lamina from the whole surface, a process that will be found very tedious, and much more difficult than the separation of the white from the black thickness. In order that the finished cameo may possess a distinct outline at all points of view, it is desirable to adopt the system followed in antique cameos, namely, to leave all the edges of the figure quite square from the ground, and not gradually rounded down to the dark surface;

(1) JURY REPORT, p. 164.

(2) The Greek name for a spiral shell, from στροβέω, *strobeo*, to twist.

should this latter method be followed, it will be found that the outline is in many places undefined owing to the colour of the white raised figure of the cameo gradually emerging into that of the dark ground: this evil is entirely avoided by leaving the edge of the figure quite square, for the thickness of about $\frac{1}{50}$th of an inch. The surface of the cameo should be finished as nearly as possible with the cutting tools, as all polishing with abrasive powders is liable to remove the sharp angles of the figures, and deteriorate the cameo by leaving the form undefined. When, however, the work has been finished as smooth as possible with the cutting tools, the final polish may be given by a little putty-powder used dry, upon a moderately stiff tooth-brush, applied with care, and rather to the dark ground than to the carved surface; this is the concluding process, after which the cameo is ready for removing from the block prior to mounting."[1]

The covering of the tortoise does not properly come under the denomination *shell*, partaking as it does of the nature of *horn*. The manufacture of that substance into combs has been treated of under COMB; some other particulars will be given under TORTOISE-SHELL.

SHELL LAC. See LAC.

SHIP. The subject of naval architecture scarcely comes within the scope of a work devoted to the details of the useful arts and the principles of civil engineering. Like architecture, agriculture, and a few other similar comprehensive subjects, it occupies a special place by itself, and requires to be treated of in a special work. The naval architect bears the same relation to the civil architect that a ship bears to a house, or to a large public building stored with all the necessaries of life, and swarming with a busy active population; but with this difference, that the ship is a floating movable structure, forming one of the connecting links between nations separated by the ocean. And it is with reference to this function that the naval architect should bring all his scientific skill to bear upon the design of the magnificent structure which he proposes to build; for as the civil architect designs his house or building with special reference to the service it has to perform, so the naval architect makes the draught of his ship with the view to ensure the preponderance of certain good qualities which may vary with the nature and dimensions of the craft.

Ship-building is both a science and an art. It is a science, inasmuch as it depends on the application of some of the great principles of nature, which cannot change: it is an art, inasmuch as it depends on the application of rules which are liable to constant fluctuation. By the application of scientific principles it is possible to ensure the attainment of a certain degree of excellence in a ship, and to cause some peculiar property to preponderate in it, such as stability, speed, &c.; and also to discover the causes of some bad quality in a ship, and to apply the proper remedy.

(1) Holtzapffel, "Mechanical Manipulation," vol. iii.

On the other hand, rules are applied where natural laws are as yet only imperfectly developed, those, for example, relating to elastic and non-elastic fluids; but it has been well remarked, that "the form of a ship's body need not of necessity remain imperfect because the curve of the solid of least resistance is unknown, since enough has resulted from the consideration of the nature of that solid to prove that, however applicable it might probably be to the navigation of smooth waters, the perfect solution of the problem of its form could only be generally desirable to the naval architect, as contributing to the theoretical perfection of the science, and would add but little to its practical utility in its application to vessels which must encounter the tremendous powers of the elements in the open seas." There are also other questions intimately connected with the resistance of fluids, such as the comparative fulness of the fore and after bodies of the ship, the positions, rakes, and proportions of the masts, the adjustment and the shape of the sails, the bracing of the yards, &c., which remain to be determined by comparison, experiment, and induction, guided by the knowledge of natural laws.

Then, again, the same principles and rules which apply to ships destined to one kind of service may be inapplicable to ships of which the service is very different. A ship whose stores are similar in amount and kind, as in the case of a man-of-war, presents fewer constructive difficulties than a merchant ship, where the lading is variable both in quality and kind. An East Indiaman, on her outward voyage, is immersed in the water 2 feet deeper than on her homeward voyage, and the draught of water in a collier is reduced at different times 4, 5, or 6 feet. These variations greatly affect the stability of the ship, as the nature and disposition of the lading influence the position of her centre of gravity. As the ship becomes lightened she loses in stability, becomes *laboursome*, and her *rolling* motion more violent, and the danger to the seamen greatly increased. Seeing, then, that under all the different circumstances of lading, the ship is exposed to the same winds and seas, it evidently requires more art to design a ship intended for purposes of commerce than for those of war.

If, then, the elements of naval construction, or the theory of ships, cannot, in our present advanced state of scientific and practical knowledge, be said to be settled, we shall be less surprised at the imperfections of the navies of earlier times. The ships of the nations of antiquity were propelled by oars, and those first employed by the maritime nations of modern Europe were *galleys* propelled by similar means. Early in the 15th century large galleys, called *carraques*, formed part of the navies of France and Spain. The vessels used by the Venetians at the battle of Lepanto were termed *galeasses*: they were long galleys, with a narrow deck running along each side of the vessel, on which small cannon were mounted, and under which the rowers sat. Previous to the reign of Henry VII. the naval force consisted only of vessels furnished by the Cinque Ports: they are said to have been a kind of long galley. But the first ship of the

royal navy, properly so called, was the *Great Harry*, constructed by the direction of Henry VII.: his successor, in 1515, constructed a ship of about 1,000 tons, carrying 122 guns, large and small: this was the *Henry Grace de Dieu:* it was better adapted for show than for use: it is said to have steered badly, and to have rolled incessantly: it only made one voyage. A similar vessel, the *Caraçon*, constructed by Francis I. of France, was not more successful. To Henry VIII. belongs the merit of forming the dockyards at Deptford, Woolwich, and Portsmouth, and organizing the Admiralty and Navy Boards. From this reign the navy began to increase in power, and at the death of Elizabeth it consisted of 42 ships of war. In 1610, under James I., the *Prince*, 64 guns and 1,400 tons burthen, was built, the largest ship up to that time: and under Charles I. was constructed the *Sovereign of the Seas*, which carried upwards of 106 guns small and great: her length was 128 feet, and her breadth 48 feet. The ships of this period were formed with very high hulls, while the lower guns were not more than 3 feet above the water; consequently the ship heeled considerably, and the lower ports could not be used when the waves ran high. But the rivalry between England and the United Provinces in the 17th century, and the desire of Louis XIV. to make the navy of France at least equal to that of his neighbours, led to the construction of ships capable of carrying guns of larger calibre than had previously been used at sea. In this and the 18th century, naval architecture was studied with much zeal and success in France and elsewhere, and the result has been the production of some noble treatises by such men as the Bernoullis, Euler, (Scientia Navalis, 1749 and 1772;) Bouguer, (Traité du Navire, 1746;) Don George Juan, (Examen Maritimo, Madrid, 1771,) and Chapman, Naval Architect to the king of Sweden, whose work, published in 1775, was translated into French by Clairbois, the author of an "Essai sur l'Architecture Navale, 1776," and into English by Dr. Inman, Professor at the Royal Naval College. Duhamel has also a treatise, entitled "Elémens de l'Architecture Navale." With all this activity on the part of continental writers, it may well excite our regret that England, whose very existence, as an independent nation, depends on the superiority of her navy, as her commerce does on that of her mercantile marine, should have so entirely neglected the study of the higher branches of the art as to be reduced to the humiliating necessity of copying the ships which her brave seamen had captured from her great rival. This servile plan was carried to such an extent that instructions were actually published for "taking the form of a ship when built." Mr. Peake introduces his description of the method of taking the form of a ship with the following remarks:—"The circumstance of many ships during the last war being captured from the enemy, of whose form no draught or drawing was in possession of the captors, and their good sailing qualities being such as to make them a desirable guide for English naval construction, it was the practice to have such vessels placed in a dry dock and their forms taken off by a draughtsman, and a drawing upon the usual scale made of them." England has not produced one original scientific treatise on naval architecture, but only a few detached papers by Mr. Attwood, Dr. Young, and others. In 1754 a practical treatise by Mungo Murray, a working shipwright at Deptford, attracted some attention. There are also similar treatises by Hutchinson, Stalkart, and others.[1] Attempts have been made, from time to time, to remedy this theoretical ignorance. Thus, in 1791, a Society was formed in London "for the Improvement of Naval Architecture:" prizes were offered by this Society for the best papers on the resistance of fluids, on designs for vessels, on the proportions of masts, &c. In 1811, a school, under the superintendence of Dr. Inman, was attached to the Naval College at Portsmouth, for instructing young men in those branches of science which relate to naval affairs, and also in the mechanical operations required in building a ship. The praiseworthy object of this undertaking was to introduce into the national dockyards a better and more skilful description of shipwright officers, for which purpose the students, on the expiration of their apprenticeship, if properly qualified, were to be eligible to all situations in the ship-building department, and if there were no vacancies they were to be employed in the royal yards as supernumeraries until vacancies should occur. We regret to say that this promising experiment has completely failed: either from the jealousy of the officers filling stations in the dockyards, being inferior in education to the pupils of the school, or from some other cause, very few appointments were made, and the supernumeraries were allowed to remain as such, exercising some influence, let us hope, although in an inferior capacity, in diffusing a knowledge of the true principles of their art. The School of Naval Architecture was abolished in 1832, so that after the lapse of nearly half a century, the Report of the Board of Naval Revision made in 1806 still applies, viz. that "nothing can be more surprising than that, in a nation so enlightened as this is, and whose power, importance, and even safety, depend on its naval superiority, matters so essential to the preservation of that superiority should so long have been neglected."

The most essential conditions required in a ship

(1) There is also a "History of Marine Architecture" by Charnock. Also the "Elements and Practice of Naval Architecture," by John Knowles, accompanied by a folio atlas of plates. "The Naval Architect's Portfolio," by Lieut. H. A. Summerfeldt, of the Royal Norwegian Navy. There is also a treatise on naval architecture, in Rees's Cyclopædia, accompanied by numerous copper-plate engravings; but perhaps the best among the modern treatises is that in the last edition of the Encyclopædia Britannica. There is a short but comprehensive article on the theory of the Ship and on the Practice of Ship-building in the Penny Cyclopædia; but the cheapest and most accessible treatise is that published in Weale's Rudimentary Series, entitled, "Rudiments of Naval Architecture," &c., by James Peake, Assistant Master Shipwright, H. M. Dockyard, Woolwich, and formerly of the School of Naval Architecture, H. M. Dockyard, Portsmouth. Parts II. and III., published separately, contain the "Practice of Ship-building." There is also in the same series, and intended as a supplement to Mr. Peake's excellent little work, a "Rudimentary Treatise on Masting, Mast-Making and Rigging of Ships," &c., by Robert Kipping N. A

are, that it shall conveniently carry its stores, artillery or lading; that it be moved by wind or by steam with great velocity; and that it readily obey the motion of the rudder; that it have the proper *stability*, so as not to be overturned when acted on by the wind and waves, and that its rolling or pitching be attended with as little strain to the timbers as possible. Some of these qualities are inconsistent with each other, so that the architect has to find a construction such as will allow the quality most required to be fully obtained, without too great a sacrifice of other desirable qualities. The form which probably unites the several qualities in the highest degree is thus described:—"The body of a ship about its middle has nearly the form of a portion of a hollow cylinder, with its axis horizontal and its convex surface downwards. Above the surface of the water on which it floats, the sides are curved, so as at the head to have, in a horizontal direction, the form of a Gothic arch more or less acute. The breadth diminishes gradually towards the stern, which above water is either a plane surface nearly perpendicular to the ship's length, or, according to Sir Robert Sepping's construction, curved so as to have in a horizontal section nearly the form of a semi-ellipse. Below the surface of the water the body of the ship is curved in a horizontal direction towards the head and stern, so as to terminate at those places in angles which diminish from that surface downwards; and thus a vertical section, taken perpendicularly to the length of the ship, at some distance from the middle, towards either extremity, presents on each side the form of a curve of contrary flexure."

In merchant ships, great capacity is often of more importance than velocity in sailing, and hence in such ships the relations between the length, breadth, and depth depend less on hydrodynamical principles than in ships of war.

The theory of a ship depends upon very simple principles, such, for example, as that involved in the proposition that a body floating at rest upon a fluid also at rest, displaces as much of the fluid as is equal to the weight of the body. Thus the weight of the water displaced by a ship floating on it at rest, is equal to the weight of the ship and all its contents. The weight of the volume of water which would fill the space occupied by the ship below the general surface of the water on which she floats is called the *displacement*. To obtain the total weight of the ship, therefore, all that is necessary is to ascertain the weight of this volume of water. Now, it has been found by calculation that the number of cubic feet in a homogeneous solid, is equal in bulk to that part of the body below the surface of the water; multiply this number by the sp. gr. of the water, *i. e.* by the weight of 1 cubic foot, the result will be the weight of water displaced, and consequently also that of the ship.

Now the ship must evidently not be so far immersed in the water as to render the armament of a war-vessel, or the lading of a merchantman, oppressive. The bulk of a ship is in proportion to her length, her breadth, and her depth, and this serves as a guide to her proportions when the displacement is known. The next step is to delineate the form and area of the transverse vertical section at the largest part of the ship's body, generally extending from the middle of the length for some distance towards each extremity: this is the *midship* section, and on its area principally depends the direct resistance which the vessel will experience, while the stability or resistance to inclination, and the easiness or uneasiness of her motions, are greatly dependent on her form. The next point is to determine the area and form of a horizontal section at the surface of the water, called the *load-water section*, or *plane of flotation*. On this greatly depends the stability of the ship in proportion to her dimensions. Her depth in the water, and the shape of the vertical section through the longitudinal axis of the ship, is next determined, and then the transverse vertical section of the body between the midship section and either extremity of the vessel, generally at parts where the body is intended to alter materially from the form of its midship section to that of a more sudden curve at the extremities.

The principal drawing or draught of a ship consists of three plans mutually dependent on each other. They are sectional planes passing through the largest portions of the ship, and are named the *sheer plan*, Fig. 1950, the *half-breadth plan*, Fig. 1951, and the *body plan*, Fig. 1952. The sheer plan is a projection on a *vertical longitudinal* plane dividing the ship into two equal parts. This plane passes through the middle line of the vessel, from the middle line of the stem or fore boundary, to the middle line of the stern post or after boundary. The half-breadth plan describes half the widest and longest level section in the ship, or that of a horizontal plane passing through the length of the ship at the height of the greatest breadth. The body plan describes the largest vertical and athwart-ship section of the ship: it forms the boundary of all the other sections delineated within it.

Considering, therefore, the ship as a solid of three dimensions, the three plans above noticed will depend upon each other, thus:—

The sheer plan gives the height and length The half-breadth gives the breadth and length	In which the *length* is common to the two.
The sheer plan gives the length and height The body plan gives the breadth and height	In which the *height* is common to the two.
The half-breadth gives the length and breadth . . . . The body plan gives the height and breadth	In which the *breadth* is common to the two.

The drawings of the required elevations and sections are usually on a scale of $\frac{1}{4}$ inch to a foot, and when these are settled and agreed upon, enlarged copies of them are made to the full size of the objects which they represent, and are traced with chalk on the floor of a room called the *mould-loft*. This operation is termed *laying off*, and its object is to supply the workmen with the exact shape and proper positions of the principal pieces of timber in the intended ship. If the floor is sufficiently spacious the ship is laid off in one length; but the floor is usually equal to half the length of the largest ship, and of the whole height of

the hull in addition. The plan being laid down, the timber ribs or *frames* are marked in their proper places, and pieces of plank, $\frac{3}{4}$ inch thick, are cut to the forms of the timbers; these are called *moulds*, and they serve as patterns for cutting, or *converting* the timber, certain marks being made on the moulds to indicate the directions in which the sides of the timbers are to be cut.

The principal lines employed in constructing a draught as well as in laying off a ship are the following, viz.:—*Water lines*, which in the sheer plan are straight lines drawn parallel to the surface of the

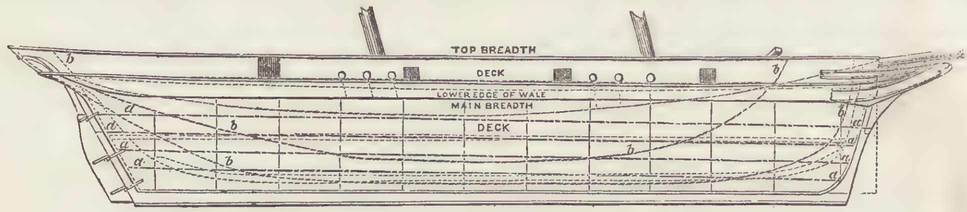


Fig. 1950. SHEER PLAN.

a, water lines. *b*, bow and buttock lines. *c*, diagonal lines M.B. main breadth. T.B. top breadth.

Fig. 1951. HALF-BREADTH PLAN.

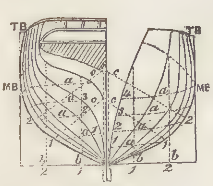


Fig. 1952. BODY PLAN.

water, and in the half-breadth plan they show the form of the ship by the successive breadths marked at heights corresponding with the water lines in the sheer plan. These lines are marked on the practical drawing in *blue* ink, and the upper water line in the half-breadth plan is the line of flotation. *Level lines:* these are similar to water lines, only they are drawn parallel to the keel instead of the water. It should be observed that the keel of a ship is not horizontal, or parallel with the water lines, or plane of flotation, but is lower towards the stern, in order to allow greater length to the rudder, so as to increase its power in directing the ship's motion. *Diagonal lines* show the boundaries of various sections formed by planes which are oblique to the vertical longitudinal plane, and which intersect that plane in straight lines parallel to the keel. These lines are drawn in *red* in the body plan of the draught, where they usually denote the heads and heels of the timbers. *Buttock* and *bow lines* are the boundaries of the vertical section of the ship parallel to the vertical longitudinal plane. The *main breadth line* is the boundary of the widest part of the ship in each of the three plans. The *top breadth*, or *top timber line*, in the sheer plan, is a line drawn to the sheer of the ship, fore and aft, at the height of the underside of the gunwale amidships; and the *top side line* is a sheer line drawn above the top timber line at the extreme height of the side of the ship. The *cutting down line* is a curve in the sheer plan, corresponding

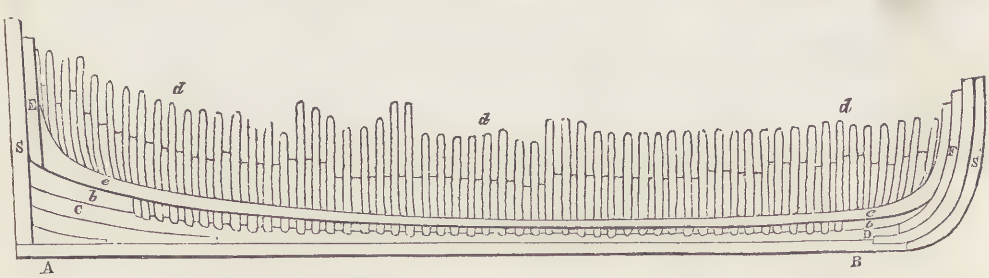


Fig. 1953. ELEVATION OF SHIP'S TIMBERS.

to the upper surface of the throats of the floors amidships, and to the under side of the keelson.

The ground on which the ship is built, called the *building-slip*, is situated by the side of a river, or other water sufficiently deep to receive the ship when she is ready to be launched. The ground is arranged in the form of an inclined plane descending towards the water. The first operation is, to place on the slip a row of blocks of oak, 3 feet high and 4 feet apart, in the direction of the length of the intended ship, the upper surfaces of the blocks forming an angle of about 3° with the horizon. On these blocks is laid the keel A B, Fig. 1953; it is the lowest timber of the ship, and upon it the whole fabric is raised: it is usually of elm, a wood which is not injured by immersion in water; its fibres are tough, and are well adapted to receive the numerous fastenings or bolts which pass through it. In a first-rate man-of-war the size of the keel is 20 inches square. In most ships the keel is composed of several pieces of timber scarfed together,

as many as 11, 12, or 13 being used in a first-rate, the after one being of oak. Pieces of elm from 4 to 6 inches thick are worked below the main keel throughout its whole extent, and form what is called the *false keel*, the object of which is to give the ship greater immersion to prevent lee-way; and in the event of the ship grounding in shallow water, the false keel, by being forced off, may thus free the vessel from danger. On each extremity of the keel, and extending towards its middle, timbers called the *dead-wood* are placed, as at C and D, and the upper surface of the dead-wood is cut into a curvilinear form *b b*, with which line the bottom of the ship's body is made to coincide. At each extremity of the keel a post is set up, that at S being called the *stern-post*, and that at S′ the *stem-post*, which is curved near the bottom. In large vessels the stem is made up of 3 pieces, known as the *upper*, *middle*, and *lower* pieces: they are united to each other and to the fore-end of the keel by means of scarfs, or with coaks[1] and copper bolts. The scarf, which unites the stem with the keel, is termed the *boxing*. See Fig. 1961. The stern-post is usually of oak, and if timber of sufficient size can be obtained, it is in one piece, solidity being required on account of its having to support the rudder. The lower end or heel of the stern-post is inserted into the after-piece of the keel by tenons or teeth, fitting into mortices in the upper and after part of the keel, as shown in Fig. 1954.

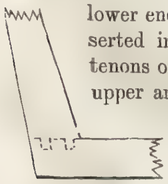


Fig. 1954.

The ribs or *frame* of the ship are composed of a large assemblage of timber, consisting of *floors, cross-pieces, half-floors, floors short and long armed, first futtocks, second futtocks, third futtocks, fourth futtocks, fifth futtocks,* and *top timbers*. The sides and upper portion of the keel and dead-wood are cut for the reception of the floor timbers, which are placed across the keel perpendicularly to its length. The floor timber is shown in section *a b c d*, Fig. 1955, *e f* being the middle line of the ship; and in order to steady it in crossing the keel, a piece of timber called the *rising wood*, *g i h k*, is worked into the seat of the floor and into the keel, the points *i* and *k* fitting the upper edge of the rabbet of the keel. The rising wood is not always used, the floor being steadied by means of a coak passed into both the floor and the keel, as at *e*.

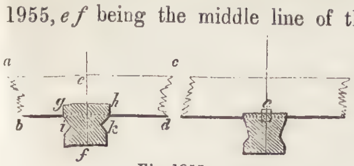


Fig. 1955.

As the economical conversion of the timber is of importance in so costly a structure as a ship, various plans have been contrived for arranging the frames. One plan was to place a half-*shift*[2] or butt on one side of the central line, and a whole shift on the other, and so on alternately. The plan introduced by Sir Robert Seppings was, to place a cross-piece or short floor across the keel, with two timbers or half-floors meeting at the middle line of the vessel, and secured to the cross-piece by dowels or circular coaks, as shown in Figs. 1956, 1957. The timbers which

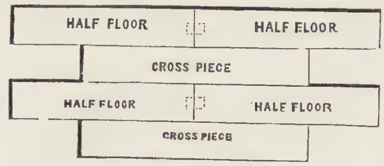


Fig. 1956.

Fig. 1957.

Fig. 1958.

join the cross-pieces or floors are the first futtocks, dowels or tenons of hard wood being placed in the heads and heels of the respective pieces, as in Fig. 1958. In merchant ships the first futtocks run down to the side of the rising wood or dead-wood, so as to leave what is called a *water-course* of the breadth of the keel or of the rising wood, as in Fig. 1959. The second futtocks are placed on the heads of the half-floors, and the third futtocks on the heads of the first futtocks, the fourth futtocks on the heads of the second futtocks, the fifth futtocks on the heads of the third, and the top timbers on the heads of the fourth timbers, and these, with the top timbers and lengthening timbers, form the *frame*.

Fig. 1959.

In merchant ships, the heads and heels of consecutive timbers are united by choaks, as shown in Fig. 1960. This plan favours the economical conversion of the timber, the choak supplying the deficiency of the timber required to form a square butt. It is stated, however, that the introduction of choaks subjects the frame to early decay.

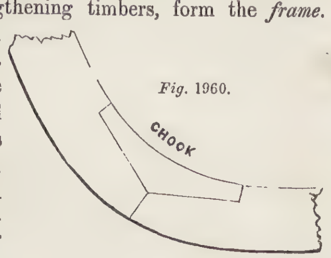


Fig. 1960.

The weight of the hull and the strength of the ship depend greatly upon what is called the *room and space*, or the distance between the frames. This varies in the Queen's service from 2 feet 6 inches to 3 feet 9 inches. The weight of the hull should be as small as

(1) For various methods of uniting timbers we must refer to CARPENTRY—FLOORS and PARTITIONS. In the latter article, Fig. 984 shows the method of joining timbers and preventing them from slipping upon each other by means of *keys* or *coaks*.

(2) The term *shift* usually refers to a certain arrangement among the component parts of a ship. Thus, *shift of plank, shift of dead-wood,* &c. is the disposition of the butts or butt-ends of the timber or planking. In a more limited sense, the term *shift* is the distance apart of two neighbouring butts or scarfs.

possible consistently with strength, for the smaller this weight the less is the displacement, and consequently the resistance to the propelling power of the sails being diminished, the speed is increased. When the spars are determined they are marked on the keel by a long measuring rod called a *station*, or *room and space staff*, and the various timbers of each frame as they are built up are kept at the stipulated distance from the timbers of the contiguous frames. The timbers of the frames above the surface of the water are nearly rectilinear, but below that plane they are of various curvatures, being at bottom nearly the form of a semicircle about the middle of the ship, while towards the head and stern they form curves of contrary flexure, uniting on the keel, with their lower concavities towards the exterior of the ship.

Within the stem is a timber called the *apron*, Fig. 1961. It is a continuation of the fore dead-wood, just as the stem is a prolongation of the keel: it strengthens the stem, and affords wood for the reception of the plank of the bottom and the heels of the foremost timbers. As a further support to the stem, the *stemson*, shown in Fig. 1953, is worked in. The inner post is a continuation of the after dead-wood, and forms a foundation for the reception of the plank, and receives the heels of the extreme after timbers. For the method of raising up the frames, cutting down the floors, and other particulars, we cannot do better than refer to Mr. Peake's instructive little work. The floor timbers are secured in their places by the *keelson g h*, Fig. 1962, and H, Fig. 1963: its

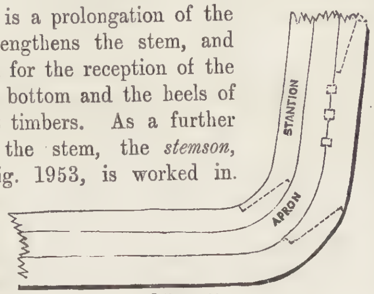


Fig. 1961.

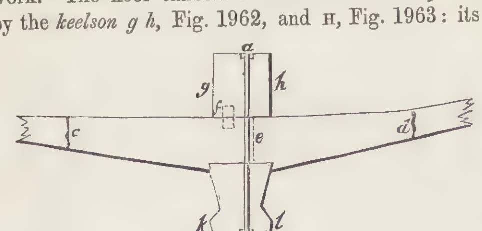


Fig. 1962.

form is square, and its siding or width is that of the keel *k l: c* and *d* are the heads of the cross-piece, *e* the butt of the half-floors placed on one side of the middle line to allow a coak *f* to be inserted clear of the butt *e*, while a copper keelson-bolt *a b* is passed also on one side of the middle line through the keelson, cross-piece, and keel. In large ships, 2 additional keelsons, G, Fig. 1963, called *side* or *sister-keelsons*, from 30 to 50 feet long, are bolted to the floor timbers sufficiently near to one another that the *step* or foot of the mainmast may rest upon them.

The timbers of the ship are covered on the outside, and also partly on the inside, with planks of oak from 3 to 6 inches thick. The outer planking is represented in section, Fig. 1963. The planking is fastened to the ribs by means of bolts and trenails, or plugs of oak, which pass through the ship's side, and are tightened by means of wedges driven into them at each extremity. But, before the planking is applied, the intervals between the frames on either side are filled up with pieces of wood 3 inches deep, and as long as the curvature of the timbers will allow, the lines of juncture with the timbers being well caulked. The spaces between the exterior and interior pieces are also sometimes filled up with cement, at least as high as the plane of flotation, so that in the event of the ship striking on a rock, and the outside planking being torn off or damaged, the vessel would still float. This plan, proposed by Sir Robert Seppings, also adds to the strength of the ship by the introduction of a solid mass of material below the water-line. "It is found in practice," says Mr. Peake, "from the form given to the bow and quarters under the water, being fine or sharp, to ensure velocity in sailing, that these extreme portions of the ship are not water-borne; and that thence the midship volume displaced must, to make up the whole displacement or weight, be on the contrary greater than equivalent to the weights placed over it. The results which arise from this inequality between the superincumbent weights and the upward pressure of the water are practically evidenced by the falling of the extremes and the rising of the middle of the vessel, causing the keel of the ship, after she has been some time afloat, to assume a curved form, which is technically called *hogging*. To take this altered position in the water, theory points out, and experience confirms, that the materials below a certain point in the depth of the vessel must have been forced into a closer contact with each other, and that thence the more dense the materials used and the more perfect their combination in building, the less alteration there would be in the form of the vessel when floated." To produce this firmness of fabric the openings below the water between the frames or ribs of the ship were first filled with bricks and mortar between cants of wood, then with a cement made of sand and water, or sand and coal-tar; but these fillings were found to lead to the decay of the frame timbers, and were abandoned for sound and well-seasoned fillings of wood, as above noticed. They are so arranged as to form a water-course under the internal planking for the drainage of water arising from leakage or other cause to the limber passage along the keel, and pass to the pump-well. These channels or water-courses are covered with planks or battens, as shown in Fig. 1963. For merchant ships, Sir Robert Seppings recommended strakes or courses of thick planks, extending longitudinally through the ship along the interior sides of all the ribs, and covering the abuttings of the futtock pieces in each alternate rib. The same surveyor also introduced a diagonal trussing into ships for the purpose of preventing the arching or hogging already noticed, but this diagonal framing was found to be of no great value as a truss; it interfered with the stowage in the hold; and was subject to early decay, inasmuch as old ship timber was used for the purpose. As a substitute for this plan iron plates were introduced for tying the frame

timbers to each other, and they still continue in use. They vary in size from $\frac{3}{4}$ to $1\frac{1}{2}$ inch in thickness, and from 3 to 6 inches in width: and they sometimes extend in length from within a short distance of the keelson to the top-sides or upper part of the vessel.

The beams B B, Fig. 1963, which receive the decks or platforms of the ship, are supported at their extremi-

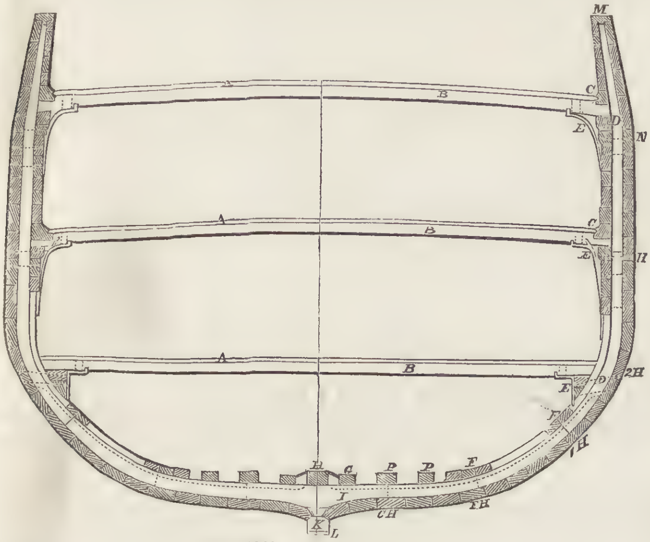


Fig. 1963. MIDSHIP SECTION.

A, decks or platforms. B, beams. C, waterways.
D, shelf-pieces. E, iron knees. F, strakes.
FH, 1H, &c. heads and heels of the frames. G, limber strakes. H, keelson.
I, fillings between the timbers of the frame. K, keel.
L, false keel. M, rough tree-nail.
N, wales, or thickest planking. P, bearers for the boilers of a steam vessel.

ties on internal longitudinal ribs called *shelves*. These shelves are usually worked before the outside planking is brought to, and may be regarded as portions of the internal planking of the frame. And now that the frame is so far complete, the *skinning* or planking is put on, for which purpose the frame is set perpendicular by dropping a plumb-line from the centre of the cross pauls,[1] when the point of the brass or plumb should coincide with the middle line of the ship, marked in upon the upper side of the keelson. If it does not so coincide, the shores are adjusted as required. The *bends* or *wales* are usually of English oak called *thickstuff*, and varying from $4\frac{1}{2}$ inches to 10 inches in thickness. As the trees which furnish the planks are wide at the butts or lower ends, and narrow at the top ends, the planks are of a corresponding form, and are worked *top and butt*, as it is called, the

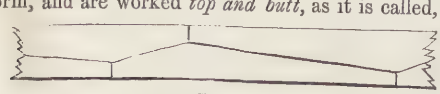


Fig. 1964.

butt of one plank being brought to the top of the other, so as to make up a constant breadth in two layers, as shown in Fig. 1964. The planks having been

(1) The cross pauls are long pieces of plank with the breadth of the ship at particular stations marked on them, and secured to the timbers at their stations to preserve the form of the ship while in frame and until the beams are crossed.

hung to the frame, the holes are all bored and left open for a time to the draught of air, so that the juices may be drawn off, and the timbers be well seasoned. Trenails are used for the fastenings, as already noticed, although copper bolts have also been employed.

With respect to the inside planking, the first band from the keelson is termed the *limber strakes*, G, Fig. 1963; but a space is left, as already noticed, between the side of the keelson and the lower edge of these strakes, to form a gutter for drainage. A rabbet is taken out of the lower of these strakes to receive the limber boards, or *plates* when of iron, which keep the dirt of the hold out of the gutter or limbers, that it may not be drawn into the pump well, and choke the pumps. In a large ship there are usually 3 strakes on each side. Next to these are the planks F, worked over the heads of the floor-timbers, and the heads of the first futtocks, to prevent the heads and heels of these timbers from being forced in. From 2 to 4 strakes are placed over each line of heads and heels in midships, and they are reduced in size and number at the fore and after parts of the vessel.

The beams resemble the rafters of a house, inasmuch as they support the floors or decks; but they do not act as a tie to the sides of the ship to prevent them from falling outwards or spreading: on the contrary, when loaded with weights, such as the guns of a man-of-war, the decks act as a thrust, tending to force the sides of the ship outwards. The beams are not flat, but are set to a *round*, or portion of a large circle, and the decks, when placed on them, partaking of that round, throw off the water from them when the ship is upright, into the side, where holes called *scuppers* are placed to convey it away. In small vessels the beams are formed of one piece of timber; but in larger ships neither their length nor their width and depth (technically their *siding* and *moulding*) admit of their conversion in one piece: 2 or 3 pieces are therefore scarfed together, the length of the scarf being $\frac{1}{3}$th the length of the beam.

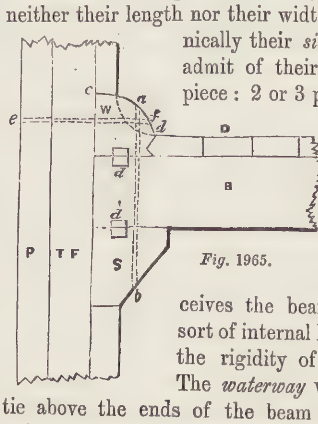


Fig. 1965.

The *shelf* S, Fig. 1965, which receives the beam-ends, acts as a sort of internal hoop, and increases the rigidity of the ship's frame. The *waterway* W, forms a similar tie above the ends of the beam B, the two being united by dowels *d d'*; and a bolt, *a b*, is run

through the shelf, beam-end, and waterway, while another bolt, *e f*, is passed through the waterway, frame-timbers T F, and outside plank P. On gun decks the curve *c d* of the waterway, was found to interfere with the training or pointing of the guns, and the convex curve *c d* was converted into the concave, as indicated by the dotted line.

The inside planking immediately under the shelf is called the *clamps*, and that over the waterways the *spirketting*. To prevent the beam-ends rising off the shelf-pieces when the vessel is rolling in a sea-way, the spirketting should be dowelled to the timbers of the frame: this plan strengthens the waterways which form the upper abutment of the beam-ends. The space between the clamps and spirketting is shut in with thin planking, called *short stuff*, between the ports which, according to Seppings' system, was worked up as a truss-frame *a*, Fig. 1966, abutment pieces *b* being

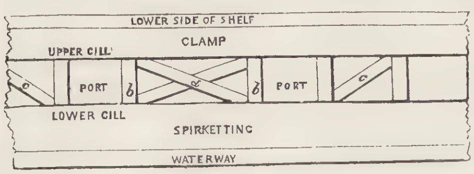


Fig. 1966.

worked at the sides of the ports. In the spaces between the after ports the truss is reversed in position as shown at *c c*.

The connexion of the waterway, beam, and shelf with the frame of the ship, as above described, gives sufficient strength for merchant vessels, but is not adequate to the wear and tear of a man-of-war, loaded with heavy guns, under a heavy sea or a press of canvass. Many plans have been proposed to prevent the working of the beam-ends from the ship's sides: iron *knees* are commonly used for uniting the beam-ends to the ship's sides, and for uniting the two sides of the ship at the head and stern; in the cant-bodies, where the floors or lower timbers do not cross the keel, inside timbers are worked: those in the fore are termed *breast-hooks*, and the after ones *crutches*.

The deck beams having been adjusted on the shelves, the knees worked to them, and the waterways placed over them, the framing of the deck is the next consideration. Doorways, trap-hatches, and mast-holes have to be provided for. The mast-holes are of larger diameter than the masts at their several heights, by double the thickness of the wedge which holds the masts in position, and these wedges vary in thickness from 3 to 6 inches. The framing for a mast-hole with wedges consists of *fore and aft partners*, *cross partners*, and *corner chocks*. The *hatchways*, or doorways from one deck to the other, are formed of 4 pieces: the two placed fore and aft are called *coamings*, *a a*, Fig. 1967, and those athwart-ship *head ledges*, *b b*. The head ledges rest on the beams, and the coamings have pieces of wood named *carlings*, *c*, placed under them, and extending from beam to beam. The ladder ways are framed in a similar manner, and on the deck, exposed to the weather, are skylights and framings for the galley or cooking range, worked in a similar manner. Included in the framing are the *riding bitts*, in the fore, for receiving the cable when the ship is riding by her anchor. These bitts are placed on the deck immedi-

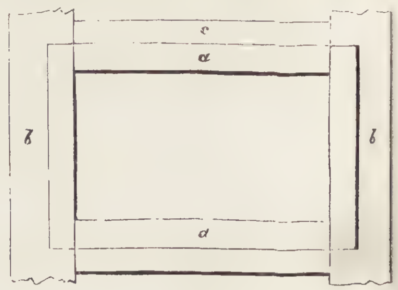


Fig. 1967.

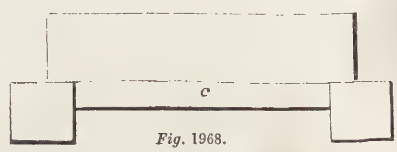


Fig. 1968.

ately above the water, such as the lower deck of a line-of-battle ship and the upper deck of a frigate. In a merchant vessel the windlass does the duty of the capstan and riding bitts.

The use of the waterway has already been explained. In addition to this there is a plank, called the *thin waterway*, 1 inch or more thicker than the thickness of the deck, worked with one edge into a rabbet formed in the main waterway, the inner edge being reduced to the thickness of the deck plank. The use

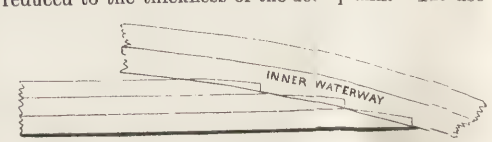


Fig. 1969.

of the thin waterway is to receive the ends of the decks as shown in Fig. 1969. The ports, Fig. 1966, or oblong holes in the sides, in which the guns are worked, and out of which they are fired, are closed up in stormy weather by *port-lids*, which in large vessels close the port-hole in one piece, and are hung with the hinges *h*, Fig. 1970, on the upper side; they are held up by the ring-bolts z z, which receive the port-pendants, or rope, or chain, and when let down they are secured on the inside by the bolts *b b*, and light is admitted by the illuminator *l*. But the more sensible plan is now adopted of fitting Mr. Lang's air-scuttles between the ports instead of the illuminator. On the upper deck the ports are in 2 parts: the lower one is hung with hinges on its lower part, and is called a *bucklar*, and the upper part is a *half-port*, to put in by hand.

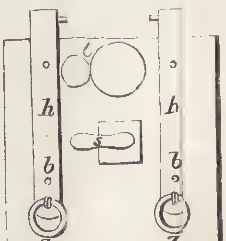


Fig. 1970.

The joints or *seams* of the external planking are made water-tight by forcing into them spun threads or layers of oakum, formed by picking to pieces old ropes and cables cut into short pieces termed junk. The seams of the planking are, if required, opened by sharp iron wedges, called *reeming-irons*, which are driven in by a beetle or mallet. The effect of these wedges is to close the seams above and below the seam which is being operated on, and thus bring a strain on the fastenings of both planks. The oakum is forced into the joints by means of sharp iron wedges called *caulking-irons*, and should any of the planking be forced off in this severe operation, the shipwright puts in additional fastenings before the caulking is completed. When the stipulated number of threads of oakum has been forced into the seams, the whole is more firmly bedded or *horsed up* by two men, one of whom holds, by means of a handle, the *meeking* or *making* iron to the caulked seam, while the other man drives it in with the beetle. The seams are now payed with melted pitch, applied by means of small mops; and, lastly, as high up the bottom of the ship as the copper sheathing will afterwards come, a thread of spun-yarn is laid in to make the seam flush or level with the planking, so that the copper sheathing may be laid on more smoothly. The bottom of the vessel, as far as the copper sheathing will extend, is also *payed up* or covered over with a mixture of pitch and tar. The decks of the ship are also caulked with oakum, but the weather decks are payed with marine glue instead of pitch.[1]

The ship, being thus made water-tight, is next launched into the water, for which purpose the slip-way on which she is built is made in the form of an inclined plane, and the upper surface of the blocks *b b*, Fig. 1971, which received the keel, and on which the ship rests during the building, is also inclined; so that the ship, during her construction, is always inclined to the horizon $\frac{5}{8}$ths inch to a foot in her length, or nearly 1 foot in 19 feet below the horizontal plane. The weight of the ship (in a 120-gun ship the hull alone weighs at least 2,600 tons) is now to be transferred from these blocks to a *cradle*, or support, arranged on two inclined planes, or *sliding ways, d d*, one on either side of the keel, and so placed on the slip that the outside of the *bilgeways* (*e e, f f*, in the following figures) or foundation of the cradle which supports the ship during the launching, shall be $\frac{1}{6}$th of the main or greatest breadth of the vessel from the side of the keel, thereby giving the bilgeways a spread from the outside of one to the outside of the other of $\frac{1}{3}$d of the main breadth of the ship and the breadth of the keel in addition. Thus the bilgeways form the support of the cradle, the cradle is the truck or carriage which bears the ship into the water, and the sliding-ways are the inclined planes down which the bilgeways slide. The sliding-ways consist of blocks of wood, on which are laid planks, which form an inclined plane about 3 feet 4 inches wide. These planks are usually laid on the blocks with close joints, but Mr. Peake recommends them to be kept an inch apart, otherwise, the air being excluded, a powerful adhesion takes place between the lower surfaces of the bilgeways and the upper surfaces of the sliding-ways. The bilgeways are about $\frac{5}{6}$ths the length of the ship, which, for a first-rate of 120 guns, 205 feet long, would be 170 feet, their breadth and depth being about 2 feet 6 inches square. Outside the bilgeways is secured a square piece of fir *g*, of about 5 inches, termed a *riband*, to prevent the bilgeways being forced outwards by the weight of the ship during the launching. The foremost piece of riband is of oak, as it forms the abutment of the after end of a piece of timber called the *dog-shore, q*, the fore-end of which butts or stops against large cleats *r* on the bilgeways, and these retain the ship on the sliding-ways until the

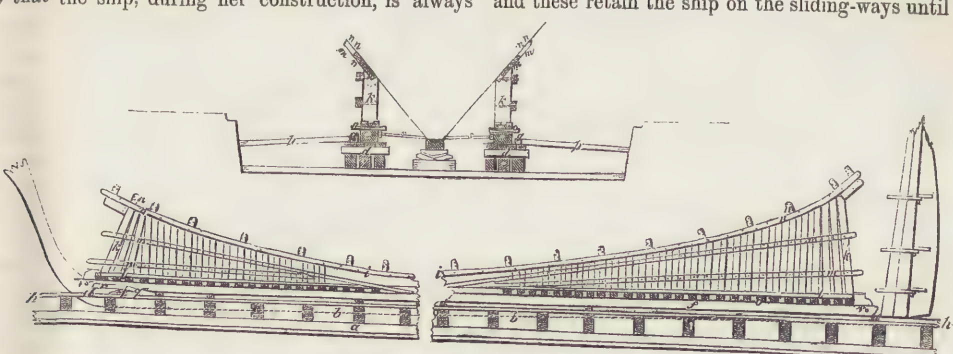


Fig. 1971. ARRANGEMENTS FOR THE LAUNCH.

time for launching. The under side of the cleat *r* should be kept above the upper side of the ribands *g*, so that in launching the cleat *r* should pass over them. A *trigger t* is placed under the dog-shore, and removed just before the launch. The foremost pieces of riband are bolted to the sliding-ways, and to prevent the bilgeways being forced inwards, shores *s* are placed on cleats from the sides of the keel to the inside of the bilgeways. To support the ribands and prevent them from spreading, riband shores *p p* are provided. The amount of inclination to be given to the sliding-ways is regulated by the size of the ship, the rise and fall of the tide, and the inclination of the building-slip. Smaller vessels require most inclination to be given to the sliding-ways, $1\frac{1}{8}$ inch to a foot being sometimes required to give an impetus to their

(1) As the caulking tends to stiffen the ship, and to increase the strain of many of the fastenings, it is sometimes the plan not to caulk the internal planking until the ship has been some years at sea.

comparatively light weight of hull. At the ends of the bilgeways are holes *v* for the reception of ropes, which are led on board the ship so as to secure the bilgeways when the vessel is in the water, when the bilgeways float up from under her.

The slide beyond the slip is laid during the recess of the tide, and the bilgeways having been placed in position under the bottom of the ship, large pieces of fir *i i*, called *stopping-up pieces*, are placed in the middle part of the bilgeways so as to meet the bottom of the ship; but at the fore and after parts *poppets k k* of square timber are secured, the heads being confined by a plank bolted to the bottom of the ship, and furnished with cleats *n n* screwed to the bottom of the vessel. The heels of the poppets rest on a plank, called a *sole-piece*, *l l*, placed on the upper side of the bilgeways. The foremost 3 poppets are placed with their heels forward, so as to act as shores to the heads of the other fore poppets. The poppets are united to the stopping-up, which is worked on the midship portion of the launching cradle by planks *m m*, called *dagger planks*. The ribands *g*, placed on the sliding-ways for confining the bilgeways, have a spread or *play* greater than that given to the bilgeways. The bilgeways are usually *turned out* the day before the launch, *i. e.* the poppets are taken down, and the stopping-pieces taken out, and the bilgeways turned over outwards, leaving their under sides to face the keel. The upper sides of the sliding-ways, and the under sides of the bilgeways, are then payed over with melted tallow, and when this is cold, soft soap or oil is added in patches. The bilgeways are now turned in, the cradle is restored and adjusted to the bottom of the ship, and on the morning of the launch large wedges *o o*, called *slices*, are placed inside and outside the bilgeways, and men, with mauls or large hammers, are stationed near them. By driving in these wedges simultaneously, they raise the hull in the cradle, or at least take its weight from the blocks on which the after part of the vessel rested during the building: these blocks thus become loose, and are removed from under the ship as the tide rises. The fore part of the cradle is not attached very firmly to the bottom of the ship; the weight rests partly on the foremost building blocks, which, as the time for launching approaches, are split out from under the ship, so that just before high-water the ship is seen, from aft, supported on 2 comparatively narrow ribands. The vessel is then christened, by dashing wine against her bows or fore part, and the word "Down dog-shore" being given, the ship glides gracefully into the waters, destined, let us hope, to assist in diffusing among the nations of the earth the blessings of peace and civilization.

The ship is, however, very far from being completed; she has yet to receive her copper sheathing, masts, rigging, &c., which could not be conveniently applied when on the building-slip, on account of her height from the ground, the inclination of the keel, and various other reasons. Moreover, the launching serves as a good test for the soundness of the naked planking. For the purpose of sheathing, the vessel is floated at high-water into dock, [see DOCK,] and being placed over the blocks prepared for her reception, the dock gates are closed, and the water at the falling of the tide is let out of the dock through drains or culverts. The vessel is secured by means of *guy* ropes and by shores of timber extending from the sides of the dock to those of the ship, these shores being gradually added as the tide falls.

It was formerly the practice to cover the immersed portions of all ships with a thick coating of pitch and tar; but this did not prevent the deposition of marine vegetable bodies on the ship's bottom, which greatly impeded its way through the water, and afforded but little protection against the sea-worm. In 1783 the ships of the Royal Navy were ordered to be sheathed with copper. The sheets are 4 feet in length by 14 inches; the lower edges of the upper sheets are made to lap over the upper edges of those below, and the after end of each sheet laps over the fore end of the one following it. The thickness of the sheathing is denoted by the weights of the superficial foot, such as 32-oz., 28-oz., 18-oz., and 16-oz. The 32-oz. copper sheathing is used round the ship at the height of the load-water line for 4 *strakes* or sheets down, and on the bows down to the keel. Of the whole number of sheets required it is usual to have ⅓d of 32-oz. and ⅔ds of 28-oz. The 18-oz. and 16-oz. sheathing is usually placed between the main and false keels, to protect the former from the worm, should the latter be torn off. Muntz's metal, noticed under BRASS, is a cheap substitute for copper sheathing. In a 120-gun ship 4,444 sheets of copper are required for the sheathing. The copper is not very durable, and in seas which contain sulphuretted hydrogen, as on the western coast of Africa, the corrosion is rapid; as it is also in the harbour of Marseilles, in consequence of the vast quantities of soap-waste poured into it from the soap factories of the town. Sir H. Davy proposed to protect the copper sheathing by attaching portions of zinc to the exterior surface, or by securing the copper by means of zinc-headed nails. A voltaic current would thus be formed, and the zinc would be dissolved in preference to the copper. The plan was successful in protecting the copper; but this being no longer dissolved, marine animals attached themselves to the ship in such numbers as to interfere with its sailing, and the plan was abandoned.

The masts of ships are usually built up of several pieces: there is a central piece in the form of a polygonal prism, to the sides of which other pieces are attached, either by means of a longitudinal projection in each, which is let into a corresponding channel in the central piece, or by blocks of hard wood let into the central and the attached pieces. The pieces are attached together, both in the fore-and-aft and in the athwart-ship direction, and they are bound together by iron hoops placed at intervals. It is a good plan to form one of the surfaces in each of 2 timbers, which are fitted together in prismatic tables, alternately elevated and depressed, so that the raised parts in each may fit into the depressed parts of the other. This arrangement enables the masts to resist the

strain of torsion to which they are subject. They are enabled to resist the pressure of the wind acting in any direction aft of the beam, by means of the *shrouds* and *back-stays*, which are secured to the sides of the ship at the *channels*, which are always placed rather aft of the mast: the shrouds can be relaxed or made *tort* by means of *dead-eyes*. [See BLOCK.] The main and mizen-masts *rake* or incline aft, but the foremast is usually upright. The stays assist in keeping the masts steady, and in resisting the pressure of the wind when its direction is before the beam, and the strain produced by the men on the braces. The fore-stay and the maintopmast-stay are in one line, as are also the main-stay and the mizentopmast-stay. "The stability of a ship depending much on its breadth, and the lateral action of the wind on the sails being the force to which the stability is opposed, it follows that the heights of the masts or sails and that of the common centre of gravity of the latter, ought to vary with the breadth of the ship; while the breadths of the sails must vary with its length. Now the momentum of the wind in the sails depending upon the breadth and height of the sails and upon the place of their centre of gravity, that momentum must vary with the length of the ship and the square of its breadth; hence in small ships it is less proportionally to the stability than in great ships; and on this account the heights of the masts in the former are generally less in proportion to the breadth than in the latter. The rudder serves to govern the ship's motion; for on being turned so that its plane is in a position oblique to the plane of the masts and keel, the reaction of the water against it as the ship advances, being resolved in a direction perpendicular to the last-mentioned plane, becomes a force which causes the ship to turn upon a line passing through its centre of gravity. Thus, by giving the rudder more or less inclination to the said plane, the ship may be made to move in any required direction, or may be made to avoid an object by which its safety might be endangered."

The term *rigging* is applied to the general assemblage of ropes employed to support the masts, and to extend or reduce the sails or arrange them so as to meet the wind. There are various kinds of rigging, such as *standing-rigging*, consisting of *shrouds*, *stays*, and *back-stays*, used for supporting the masts, and occupying a fixed position in the ship. *Running-rigging* consists of *braces*, *sheets*, *halliards*, *clue-lines*, &c., and is used for arranging the sails, for which purpose it is passed through various blocks arranged about the masts, yards, shrouds, &c. The *lower rigging* is that used for the lower masts, and the *topmast rigging* includes the topmast shrouds, stays, and back-stays.

The class of vessel under consideration is greatly determined by the arrangement of the masts and rigging. Thus the term *ship* is applied to those vessels which have a *fore*, a *main*, and a *mizen* mast, with a *top* mast and a *top-gallant* mast to each; and in which the yards in sailing before the wind are braced *square*, that is to say, in horizontal positions perpendicular to the length of the ship: but the mizen sail is usually in a fore-and-aft position, *i.e.* in a vertical plane passing through the keel. If the mizen-mast carries no top-sail or top gallant sail, the vessel is termed a *barque;* but in other respects the masts and sails are similar to those of a ship. A *brig* has no mizen-mast; but only a fore and a main-mast, with top and top-gallant masts and sails like those of a ship: the position of the main-sail corresponds with that of the mizen-sail in a ship with 3 masts. A *snow* is rigged in the same manner as a brig, except that the main-sail is attached to a small mast abaft of, and very near the main-mast. A *schooner* has two masts, and the sails, in their usual position, are in vertical planes, passing through the keel: it has no top-sails. A *sloop* or *shallop* has only one mast with a main-sail, the plane of which is usually in a fore-and-aft position. All the above varieties have each a *bowsprit*, carrying a forestay-sail and a jib-sail.

In the British Navy the term *line-of-battle ship* is applied to ships which carry 70 or a greater number of guns. A *frigate* has generally 2 decks and carries from 36 to 60 guns. Frigates are built narrower than line-of-battle ships in proportion to their length, and are swift sailers. Ships of war of a lower class than frigates are termed *sloops* and *corvettes*, carrying from 4 to 20 guns: *brigs*, *cutters*, *brigantines*, *ketches*, *schooners* and *barques*, none of these carry more than 10 guns.

Vessels are now very frequently constructed of iron, and they have the advantage of being lighter and more buoyant than those of wood: they are, moreover, not so liable to become arched, and the consequences of striking upon a rock are not so fatal; for while a vessel of wood might be pierced or go to pieces, an iron vessel would only be indented. Iron ships are formed with rib-frames at intervals, and with longitudinal hoops of iron, and they are covered with iron plates attached to the ribs by bolts and rivets. The lower part of the interior is sometimes divided into separate air-tight compartments, so that, should the bottom be pierced in any one part, the water would be confined to that compartment, without endangering the safety of the ship.

With respect to the *tonnage* of a ship, this is properly "an expression for the interior capacity by the number of tons of sea-water which it could contain; therefore if the interior volume were found in cubic feet, on dividing that volume by 35 (the number of cubic feet of sea-water which are equal in weight to one ton), the quotient would be the tonnage required. The tonnage, however, is frequently understood to express the capacity by the number of tons of sea-water which might be contained between a horizontal plane passing through the ship when she floats in still water with only her equipments and stores on board, and a horizontal plane passing through the ship when laden, that is, between what are called the *light-water* and *load-water* planes; the volume of that part of the ship, expressed in cubic feet, being divided by 35, as in the other case. This result evidently gives the weight of the ship's cargo merely."[1]

(1) *Penny Cyclopædia*,—article SHIP.

Various formulæ have been at different times constructed by which an approximate value of the tonnage may be easily found. Such rules are empirical, but they are sufficiently accurate for most purposes; and they greatly abridge the laborious process of finding the tonnage by the ordinary rules of mensuration.

There are several articles in the course of this work which bear on the subject of the present article. The arrangement of lightning conductors for ships is described under ELECTRICITY. Cables are noticed under CHAIN-CABLE and ROPE. See also ANCHOR—COMPASS—BINNACLE—BLOCK, &c.

SHOT. The usual method of making lead shot resembles in some respects the natural process by which rain is converted into hail: melted lead is made to fall through the air from a considerable elevation, and thus leaden rain becomes cooled and solidified into leaden hail or shot. The method is said to have originated with a plumber of Bristol, named Watts, who, about the year 1782, dreamed that he was out in a shower of rain, that the clouds rained lead instead of water, and the drops of lead were perfectly spherical. He determined to try the experiment, and accordingly poured some melted lead from the tower of St. Mary Redcliffe church, into some water below; the plan succeeded, and he sold his invention for a large sum of money.

For the carrying out of this invention shot-towers and shot-wells have been constructed. At the top of the fall melted lead is poured into a colander, and the drops are received into a vessel of water below. In large establishments from two to three tons are melted at once. The surface of the lead becomes covered with a spongy crust of oxide, called *cream*, which is used to coat over the bottom of the colander, to prevent the lead from running too rapidly through the holes, whereby they would form oblong spheroids instead of spheres. The colanders are hollow hemispheres of sheet iron, about 10 inches in diameter. The holes differ in different colanders, according to the size of the shot. For shot known as No. 0, the holes are $\frac{1}{50}$th of an inch in diameter: for No. 1, the holes are $\frac{1}{58}$th in.; for No. 2, $\frac{1}{66}$th; for No. 3, $\frac{1}{72}$nd; for No. 4, $\frac{1}{80}$th. From No. 5 to No. 9 the diameter decreases by regular gradations, the latter being only $\frac{1}{360}$th of an inch. These dimensions are, of course, very much smaller than those of the shot produced; for the lead passes through the holes of each colander in fine threads, which collect into globules of the size of the shot on the under surface of the colander.

When the shot are taken out of the water they are dried on iron plates heated by steam. The imperfect shot are then separated by the following process. A slab of polished iron is tilted at a certain angle, and the shot are strewed along the upper part of the inclined plane thus formed. The perfect shot proceed rapidly in straight lines, and fall into a bin placed to receive them, about a foot away from the bottom of the slab. The misshapen shot, on the contrary, travel with a slower zigzag motion, and fall without any bound into a bin placed immediately at the end of the incline. By this simple contrivance the good and the bad shot are effectually separated. The shot are now of a dead silvery-white colour. They are polished and made dark in an iron barrel, or *rumble*, containing a small quantity of powdered plumbago. They are then tied up in canvass bags containing 28 lbs. each, and are ready for sale. Iron shot are formed by casting. The method of forming leaden bullets is described under GUN.

SIENITE or SYENITE (from *Syene*, in Egypt). Granite is so called when it contains hornblende in place of mica. See GRANITE—INTRODUCTORY ESSAY, page lxxix.

SIEVE. The operation of sifting is a species of filtration whereby solids of different degrees of fineness are separated from each other, or a solid is separated from a liquid. Sieves are made of various materials, but generally of some woven fabric stretched across a drum: thus there are sieves of horse-hair, of gauze, of silk, and of wire: there are also sieves of parchment perforated with holes, as noticed under GUNPOWDER. Sieves of silk are noticed under POTTERY and PORCELAIN, Sec. V. Wire sieves are made of different degrees of fineness, according to the number of wires contained in an inch. Fine sieves have sometimes as many as 120 wires to the inch. [See EMERY.] The bolting cylinders, or dressing machines of corn mills, are a species of sieve. [See BREAD, Fig. 226.] Sieves are also used for mixing as well as separating powders; but the particles must be of such size as to pass freely through the sieve. The powders being first mingled by hand or by a spatula, and then passed twice or three times through a sieve, will be very uniformly mixed.

In those manufactures in which sifting is a frequent and extensive operation, as in the pounding of drugs, the preparation of emery, &c., a *sifting machine* is a useful contrivance. It consists of a square wooden frame *f*, Figs. 1972, 1973, in which are 5 or 6 octagonal openings for the reception of common drum sieves *s s*, which are furnished with covers. The frame is suspended from the ceiling by means of 4

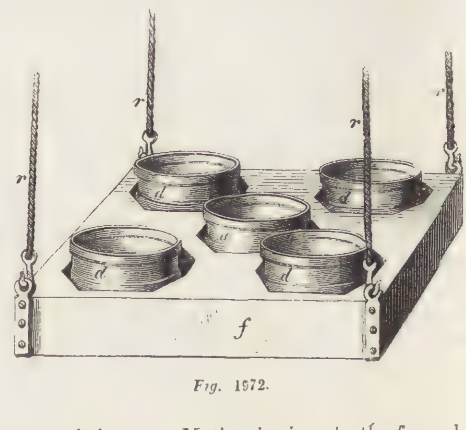


Fig. 1972.

ropes or chains *r r*. Motion is given to the frame by means of a spindle *s*, Fig. 1973, which works in a square socket in the bottom of the frame, and is

turned by a band *b*. By the joint action of the revolving crank and of the suspending ropes, an

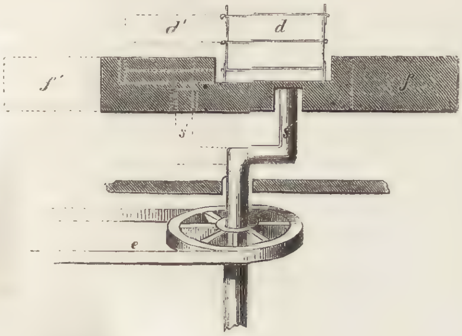


Fig. 1973.

excentric and jerking motion is thus imparted to the frame *f*, and thence to the sieves *s s*.

SILEX—SILICA. See SILICIUM.

SILICIUM (Si 15), also called *Silicon*, is the metallic or earthy basis of *silica*, *silex* or *flint*, a substance of great importance in the mineral kingdom, entering as it does into the composition of a vast number of minerals. Silicium is, next to oxygen, the most abundant substance on the earth, so far as we are acquainted with it. In fact, all the rocks which are not calcareous are siliceous. Silicium occurs in small quantities in the vegetable, and in extremely small quantities in the animal kingdom. Silicium may be obtained without much difficulty by the following process:—The double fluoride of silicium and potassium is to be heated in a glass tube with nearly its own weight of metallic potassium: a violent reaction takes place, and silicium is set free. The contents of the tube, when cold, are thrown into water, which removes the saline matter and any remaining potassium, and leaves the silicium untouched. In this state it forms a dark brown powder, without lustre: on being heated in the air, it burns and becomes coated with silica: it is acted on by sulphur and by chlorine: heated strongly in a covered crucible its colour deepens, and it becomes denser and incombustible.

The oxide of silicium or silica ($Si\,O_3$) is said to contain 21·3 parts of silicium and 24 of oxygen. The transparent, colourless varieties of rock crystal consist of nearly pure silica. Quartz, agate, calcedony, flint, and several other minerals consist chiefly of silica.

Pure silica may be obtained by the following process:—Equal parts of fluorspar and glass, both in fine powder, are to be introduced into a glass flask together with sulphuric acid. A wide bent tube is to be fitted to the flask by means of a cork, and the tube is to be passed down to the bottom of a glass jar containing sufficient mercury to cover the extremity of the tube. The jar is then to be about half filled with water, and heat applied to the flask. Hydrofluoric acid is first disengaged, which in contact with the powdered glass is decomposed with the production of water and fluoride of silicium. The latter is a gas, and escapes from the flask by the bent tube; but coming in contact with the water it is in its turn decomposed, and yields silica, which separates in a gelatinous form, and a double fluoride of silicium, and hydrogen called *hydrofluosilicic acid*. The silica is collected on a cloth filter and well washed, then dried and heated to redness. The acid liquor is a good test for baryta and potash, with which it forms nearly insoluble precipitates.

The above process may be varied by collecting the fluoride of silicium over mercury instead of conducting it into water: it is a permanent gas, it has no colour, and is very heavy: when let out into the air, it forms a thick white cloud, from the condensation of atmospheric moisture.

Pure silica may also be obtained from powdered rock crystal or fine sand mixed with about 3 times its weight of dry carbonate of soda, and fused in a platinum crucible. A vitreous mass is thus produced, which when cold is to be boiled with water, which dissolves it almost entirely. An excess of hydrochloric acid is added to the filtered liquid, and the whole is evaporated to dryness. The gelatinous silica thrown down by the acid is thus made insoluble, and remains behind, when the dry saline mass is treated with acidulated water, by which the salts of alumina, sesquioxide of iron, lime, &c., are removed. The silica is lastly washed, dried, and heated to redness.

Silica is a fine, white, tasteless powder, of the density of about 2·66. It is not sensibly soluble in water, or dilute acids, except hydrochloric acid, unless recently precipitated. It dissolves freely in strong alkaline solutions; and it can be fused by the oxy-hydrogen blowpipe.

Silica is really an acid, the *silicic*, and under favourable circumstances a powerful one; but being insoluble in water, its acid properties are not usually manifested. When heated with bases, especially those capable of undergoing fusion, it unites with them, and forms true salts, which are in some cases soluble in water; such, for example, as the silicate of potash and of soda when the proportion of the base is considerable. The important uses of silica in the arts will be seen by referring to such articles as GLASS—POTTERY AND PORCELAIN—MORTARS AND CEMENTS. See also AGATE—FLINT—SAND—QUARTZ, &c.

SILK. The discovery of the uses to which the cocoon of the silkworm might be applied, appears to have been first made in China: the written records of that country declare that an Empress was the first to unravel the filmy thread, and to work it into a web of cloth, and this is stated to have taken place 2,700 years before the Christian era. However this may be, it is a fact that when the existence of the silken fabrics of China became known in other countries, the manufacture was not in its infancy and imperfectly executed, but had attained a degree of excellence which proved a long and successful practice of it among the Chinese. Such indeed was its importance, that the very people and their country are named *Seres*, and *Serica*, in ancient writings, from the Chinese word *Se*, which signifies *Silk*.

While the most imperfect notions were prevalent in other countries as to the true nature of silk, some writers describing it as downy wool combed from the leaves of trees, the material itself in its raw state was for ages exported from China, and manufactured in Persia, Tyre, Berytus, and elsewhere, and thus the woven fabrics reached several parts of Europe and Asia. The silkworm itself was all this time unknown, except to the privileged inhabitants of the celestial empire. Aristotle and Pliny had, however, obtained tolerably accurate accounts of it. Pliny, indeed, asserted it to be a native of Kos, or Cos, one of the islands of the Grecian Archipelago; yet the fact of Pamphila, a native of that island, being the first to unweave imported silken fabrics for the purpose of spinning and weaving them anew into lighter fabrics, such as gauze, seems conclusive against his assertion. This labour of hers would have been unnecessary had the silken thread been obtainable in any other way. Her practice was afterwards adopted by the ladies of Rome. In that luxurious capital, so beautiful a material as silk only required to be known to be highly prized. In the reign of Augustus it was very little known: in the reign of Tiberius silk from the East was only worn by ladies of the highest rank, but the thinner manufactures of Cos were more general during the hot season. Men were forbidden to wear silken fabrics; but a mixed material of inferior quality, called *sub sericum,* was worn by both sexes. The great cost and difficulty attending the importation of silk to Rome, caused Marcus Antoninus, in the second century, to send ambassadors to China, with a view of establishing commercial relations with that people; but the embassy met with small success, and Rome continued to be supplied with silk, as before, by the caravans of Persia, which traversed Asia from the shores of China to the Syrian coast. The immense cost of silken fabrics may be estimated by the fact that a silken garment is mentioned as one of the wanton prodigalities of the Emperor Heliogabalus, while a dress of similar material was refused by Aurelian to his empress, on the ground that it could only be obtained by its weight in gold.

At length, about the middle of the sixth century, the western world received the great boon of a supply of silkworms' eggs: these were conveyed from China to Constantinople by two Persian monks, who had gone to the East as missionaries, and had observed in China the various processes connected with the rearing of the silkworm, the nature of the trees on which they fed, and the preparation of the silk. This occurred about the year 552, in the reign of Justinian, who gave every encouragement to the introduction of the valuable insect. The eggs were secretly conveyed from China within a hollow cane: at the proper season they were hatched, and the caterpillars were fed with the leaves of the wild mulberry-tree. The monks continued to superintend, at Constantinople, the rearing of the insects, and the whole process of manufacturing the silk. From this small commencement the myriads of silkworms have sprung which throughout Europe and western Asia have met the demand for silk, which has gone on increasing from that time to the present.

The silk manufacture thus commenced was kept in the hands of the Romans for some years; but the silkworm was gradually introduced in several parts of Greece, and the mulberry planted to supply food. The Greek empire became the great European seat of the manufacture, and continued to be so for nearly 600 years. At length Roger I. king of Sicily, having in 1147 sacked Corinth, Athens, and Thebes, carried off large numbers of the inhabitants to Palermo, where they introduced the culture of the silkworm, and the manufacture of silk. Thus Sicily became possessed of this profitable art, which soon made its way into Italy, so that Venice, Florence, Lucca, and Milan became celebrated for the beauty and extent of their manufactures in silk. Modena also produced silk, which, in 1306, was esteemed the best in Lombardy. In Venice the manufacture was held in such esteem, that the business of a silk factory was considered to be no degradation to the higher classes of inhabitants. The three trades of silk manufacturer, glass-maker, and druggist were in fact classed together as noble employments, not unbefitting the aristocracy of Venice. In the year 1300, many thousand persons were employed in the manufacture at Florence. Until the beginning of the sixteenth century Bologna was the only city of Italy which possessed proper throwing-mills, so that other cities had to send their silk there to be twisted and prepared for the weaver. Spain, as well as Italy, proved very favourable to the culture of the silkworm. Granada, Murcia and Cordova possessed numerous establishments for the production of silken fabrics.

The introduction of silk into France is assigned to Louis XI., who, in 1480, obtained workmen from Genoa, Venice, and Florence, and established the manufacture at Tours. But it did not prosper, so that in the reign of Francis I. a new importation of workmen had to be obtained from Milan. These, about the year 1521, were established at Lyons, and under the encouragement and protection of the monarch, obtained much success. The manufacture flourished, and spread to other parts of France, supplying in the course of time not only the demand of that kingdom, but a superabundance for foreign markets. England was largely supplied from thence. There are evidences of a much earlier use of silk in England as an occasional article of splendid display. Very soon after the Conquest mention occurs of silken fabrics; and on the day of the marriage of Margaret, daughter of Henry III., with Alexander III. of Scotland, 1000 English knights appeared in *cointisses* of silk, which were replaced on the following day by others equally splendid. The increased supply and more general use of silk in England, which followed on the successful progress of the manufacture in France, seems to have awakened the alarm of the rulers of this country, lest home productions should suffer from this importation of foreign goods. In the reign of Mary (1554) a sumptuary law was made, purporting "that whoever shall wear silk in or upon his or her

hat, bonnet, or girdle, scabbard, hose, shoes, or spur-leather, shall be imprisoned during three months, and forfeit ten pounds." Magistrates and persons of quality were exempted from this law. In the first year of James I. it was altogether repealed. But France was not the only neighbour who tempted England with these proscribed luxuries. The trade in silk carried on by the merchants of Antwerp was very extensive, and yet none of the costly goods were retained for their own wear. "They buy infinitely," says an old writer, "but it is to sell again. They are the great masters of Indian spices and Persian silks, yet wear plain linen and feed upon their own fish and roots. They sell the finest of their own cloths to France, and buy coarse cloth out of England for their own wear; they send abroad the best of their own butter, and buy the cheapest out of Ireland or the north of England for their own use. In short, they furnish infinite luxury which they never practise, and traffic in pleasures which they never taste." These merchants obtained the richest silks, crapes, &c. from Bologna in return for their own serges; they procured the raw, unmanufactured silken produce of Naples and of Venice in return for cloths, stuffs, and tapestries, or for jewels and pearls. Milan, Florence, and Genoa gave them silks, satins, and velvets in return for pepper, sugar, cloth, and serges. On the taking of the city of Antwerp by the Duke of Parma, in 1585, the commerce of the Low Countries was almost destroyed, and about a third part of the manufacturers and dealers in silk took refuge in England, and gave a powerful impulse to our home manufacture.

The silk throwsters of London had formed themselves into a fellowship in 1562, and were incorporated in 1629. In 1666, it was stated that no fewer than 40,000 individuals were engaged in the trade. Thus did the English manufacture steadily progress: while the importations of foreign silks, with occasional exceptions, were quite free. Prohibitions were made, during the reigns of James I., Charles I., the Protectorate, and Charles II., but they were not strictly enforced. In 1685 the revocation of the edict of Nantes drove hundreds of thousands of industrious persons from France to seek protection in other countries: some 50,000 came to England. Of these the silk manufacturers settled in Spitalfields, and introduced several new branches of their art. At this time foreign silks were freely admitted, 6 or 700,000 pounds worth being annually imported; our own manufacture at the same time was making rapid advances. But the very circumstance which appeared for a time so advantageous to the silk trade of England, namely, the establishment of the refugees in this country, led at length to monopolies and restrictions. In 1692 the refugees obtained a patent, giving them the exclusive right to manufacture lustrings and *à-la-modes*, the two fashionable silks of that day, and in 1697, their solicitations were effectual in obtaining from Parliament a prohibition, not only of the importation of all French and European manufactured goods, but of those of India and China. From this period the smuggling of silks from France became extensive, reaching, it is said, to the value of about 500,000*l.* *per annum;* the complaints of manufacturers and the vigilance of government being wholly ineffectual to prevent the evil.

At the commencement of the eighteenth century the silk machinery of this country was still so defective that our supply of thrown silk continued to be chiefly obtained from Italy. An unsuccessful attempt was made by a person named Crochet to establish silk-throwing at Derby, but the machinery was not fitted for its purpose, and the scheme failed. The next attempt was made by John Lombe, an excellent mechanic and draughtsman, who visited Italy about the year 1715 with a view to procure models and drawings of machines. But he was denied admission to silk works; and at last obtained his information by the dishonourable mode of bribing two workmen connected with a mill in Piedmont, to allow him secretly to inspect the machinery. The information gained in these visits was carefully committed to paper by Lombe each night before he slept. In this way he obtained all the knowledge he required; but he and his accomplices were discovered, and could only with the greatest difficulty and risk to their lives escape to a ship, which at last brought them all three to England in 1717. Lombe then erected his famous silk mill on the Derwent at Derby, which excited great astonishment at the time. It was 5 stories high, and $\frac{1}{8}$th of a mile in length, comprising 26,586 wheels, and 97,746 movements, which worked 73,726 yards of organzine silk thread with every revolution of the water-wheel which moved the machinery; and as this revolved three times every minute, the daily produce of organzine amounted to 318,504,960 yards. On the death of John Lombe, the proprietorship of the mills devolved on his brother William, and subsequently descended to his cousin Thomas, afterwards Sir Thomas Lombe, who petitioned Parliament for a renewal of the patent. This was declined, but a grant of 14,000*l.* was made to him, in consideration of the national benefit derived from the labours of his family. This benefit was not, however, very apparent. According to Mr. McCulloch these mills could not have been constructed unless oppressive duties had been laid on thrown or organzine silk; and the circumstance of their having been erected, and a large amount of capital vested in them, was successfully urged, for more than a century, as a reason for continuing the high duties.

From this time the progress of the silk trade may be traced in the various acts of Parliament framed with a view to promote its prosperity; but which seem to have failed in their object. The combinations and outrages of workpeople, and the dreadful sufferings to which the silk-weavers were occasionally subjected, show the impolicy of the very severe restrictions which were laid on this trade. All improvement was checked: the same loom, and the same throwing machinery continued to be used, and in several branches of the manufacture we were far behind our continental neighbours; when in 1824 the

high duty on raw silk was abandoned for one merely nominal, and that on thrown silk was reduced nearly one half. In 1826 the prohibition was removed from foreign silks, and they were admitted at a duty of 30 per cent. A rapid improvement in our machinery and manufacture immediately followed this measure, the disparity in the quality of English and French goods gradually disappeared, and in the year 1842 the value of British silken goods *exported to France*, amounted to 181,924*l*. The appearance of the goods produced by our English manufacturers at the Great Exhibition, proved the great advance made by this country during the last twenty years in the quality, design, and cheapness, of our silken fabrics. "Until within that period," says the Jury Report, "this branch of manufacture was comparatively inconsiderable, but it is now one of great importance, both as regards the quantity and value of the goods produced, and the extent of the markets opened for their sale and consumption." The silken goods of France in the Great Exhibition were magnificent and extensive.

The silkworm is the caterpillar of the mulberry-tree moth (*Bombyx mori*) belonging to the tribe of

Fig. 1974. SILKWORM MOTH AND EGGS.

mealy-winged nocturnal insects, of which in the summer evenings we see so many examples. The eggs of this moth are smaller than grains of mustard-seed, very numerous, slightly flattened, yellowish at first, but changing in a few days to a blue or slate colour. In temperate climates they can be preserved through the winter without hatching until the time when the mulberry-tree puts forth its leaves in the following spring. This tree forms the entire food of the caterpillar, and seems almost exclusively its own; for while other trees and vegetables nourish myriads of insects, the mulberry-tree is seldom attacked by any but this insect, which in many parts of its native country, China, inhabits the leaves in the open air, and goes through all its changes without any attention from man, whose only care is to gather in the harvest of silk cocoons at the right season. In some parts of China, however, the silkworm requires the same care in the way of shelter, feeding, and nursing which in other countries is found necessary to ensure success. The common mulberry-tree (*Morus nigra*), so well known in Great Britain, is not the best species for the nourishment of the silkworm, although the caterpillar feeds readily on the leaves. The white-fruited mulberry, *M. alba*, a native of China, is the best, and is greatly preferred by the insect. It is now cultivated in many parts of Europe, frequently as a pollard by road sides. It comes into leaf a fortnight earlier than the black mulberry, which is an advantage in the culture of silkworms. The white mulberry does not thrive in Britain, the winters being too severe. There is another variety of mulberry, called the *Philippine* mulberry, which is a favourite in the south of France, on account of the size and quantity of the leaves, and the ease with which it can be propagated.

In the south of Europe mulberry leaves are sold by weight in the market, and the buyer chooses them either young or mature, according to the age of the insects which are to feed on them. Young worms are fed on tender leaves, while full grown caterpillars require the stronger nutriment of the mature leaf. Attempts have been made to store food for the silkworm by drying the leaves in the sun, then reducing them to powder, and placing the latter in jars. This powder moistened with water is eaten with avidity by the silkworm; and may prove a valuable resource in late seasons, or under circumstances which affect the principal crop. It is even thought that three or four crops of cocoons per year may be obtained even in northern climates, by keeping successive hatchings of eggs in warm rooms, and supplying the worms with this food during winter.

The silkworm, when first hatched, is about a quarter of an inch long, and of a dark colour. If supplied

Fig. 1975. SILKWORM CATERPILLAR IN SEVERAL STAGES OF ITS GROWTH.

with appropriate food it remains contentedly in one spot: this is the case throughout its changes, so that there is no trouble in retaining it within bounds, as there would be with some other caterpillars. After 8 days' feeding and rapid increase of size, it prepares to change its skin, the first skin having become too small for its body. It remains 3 days without food, during which time a secretion forms on the surface of the new skin, which helps the caterpillar to cast off the old one; but the operation is further facilitated by silken lines which the insect casts off and fixes to the adjacent objects: these hold the old skin tightly, while the caterpillar creeps out of it. The whole covering of the body is thus cast off, including that of the feet, and of the teeth and jaws, but it is done with difficulty, and sometimes the skin breaks, and a portion of it remains attached to the hinder part of the body, compressing it, and usually causing death. The newly moulted worm is pale in colour, and

wrinkled; but it immediately recovers its appetite, and grows so rapidly that the new skin is soon filled out, and in 5 days another moult becomes necessary. Four of these moults and renewals of the skin bring the caterpillar to its full size, when its appetite becomes voracious, and the succulent parts of the mulberry-leaves disappear with extraordinary rapidity. The insect is now nearly 3 inches long; its structure consists of 12 membranous rings, which contract and elongate as the body moves. There are 8 pairs of legs; the first 3 pairs being covered with a shelly or scaly substance, which also invests the head. The mandibles are strong, and indented like a saw. Beneath the jaw are 2 small orifices, through which the insect draws its silken lines. The silk is a fine yellow transparent gum, secreted in slender vessels, which are described as being wound, as it were, on 2 spindles in the stomach; these vessels, if unfolded, would be about 10 inches long. The insect breathes through 9 pairs of spiracles distributed along the sides of the body. The caterpillar has 7 small eyes near the mouth; the 2 spots higher up are not eyes, but portions of the skull.

Arrived at maturity, the caterpillar is of a rich golden hue; it leaves off eating, and selects a corner in which to spin its cocoon. It first forms a loose structure of floss-silk, and then within it the closer texture of its nest, of an oval shape: here the cater-

Fig. 1976. COCOON OF SILKWORM, (*with part of the floss silk removed.*)

pillar remains working until it is gradually lost sight of within its own beautiful winding-sheet. Taking no food, and emitting this large quantity of silk, its body diminishes one-half, and on the completion of its cocoon it changes its skin once more, but then becomes an apparently inanimate chrysalis, or aurelia, with a smooth brown skin, and pointed at one end. It remains in this corpse-like state for a fortnight or 3 weeks, when it comes forth a perfect winged insect—the silk moth. In

Fig. 1977. CHRYSALIS OF THE SILKWORM.

escaping from the cocoon it pushes aside the fibres, first moistening the interior of the cocoon with a tasteless liquid from its mouth to dissolve the gum which holds the fibres together. The moth has no teeth, therefore it cannot gnaw its way out as generally supposed. In the perfect form, the insect takes no food, and only lives 2 or 3 days: the female dies soon after laying her eggs, and the male does not long survive her.

The common silkworm is not the only caterpillar from whose cocoons silk has been obtained for manufacturing purposes; but it is so superior in the quality and quantity of its silk to all other insects, that small mention is made of any other. The larvæ of many European moths produce a strong silk, and the native silkworms of America yield a material which has been manufactured into handkerchiefs, stockings, &c. by the inhabitants of Chilpancingo, Tixtala, and other places of South America. The ancient Mexicans used the internal layers of white cocoons, which strongly resemble Chinese paper, as a material for writing on. A quantity of inferior silk is obtained in India from the Tusseh and Arindy silkworms, both natives of Bengal. The first affords a coarse dark-coloured silk, which is woven into a cheap durable cloth; the second yields a delicate flossy silk, which cannot be wound from the cocoons, and is therefore spun like cotton. Of this, a coarse kind of white cloth is manufactured, which is loose in texture, but so durable that it can scarcely be worn out in a life-time.

The domestic treatment of the silkworm has been brought to great perfection in Italy. Formerly the eggs were hatched at uncertain periods, depending on the natural warmth of the season, or they were put in manure-beds, or were worn in little bags about the person next the skin. They are now hatched in an apartment heated to the proper degree by a stove; but they are first washed in water, and afterwards in wine, to separate light eggs, as well as dirt, and the gummy envelope which surrounds the heavy ones.

The temperature of the hatching-room is at first 64°, but is gradually raised 1 or 2 degrees daily, until it reaches 82°, which it is not to exceed. Pieces of coarse muslin, or of white paper pierced with holes, are placed over the eggs when they are about to be hatched. Through these the worms creep to the upper surface, and are removed as soon as possible to a cooler place. Young leaves and sprigs of mulberry are laid upon the muslin or paper, when the worms eagerly settle on the leaves, and can thus be transferred to trays, and removed to the nursery. This is a dry room of regulated warmth, with windows on both sides, so that free ventilation may be attainable. Chloride of lime should be in use to purify the air, and a thermometer and hygrometer to regulate the heat and moisture; the latter is apt to abound where silkworms are kept, and is very prejudicial to them. Moist exhalations arise from the leaves and from their bodies; fermentation, also, soon takes place if litter and dung be not speedily removed from their trays; these are fertile sources of disease among the worms, and may carry off thousands in a day.

One of the diseases to which silkworms are liable is of an extraordinary character, consisting of the formation of a minute cryptogamous plant or mildew within the body of the living insect. Damp and fermenting food and litter produce, in the first place, among the fatty matter of the body of the caterpillar, an infinite number of sporules supported by minute stems. These increase to such a degree that the vegetation soon pierces the skin, gives a general mealy

appearance to the body of the caterpillar, ripens its seed, which is borne by the winds to every part of the nursery, carrying contagion with it, and at length causes the death of the worm. The dead bodies of worms or moths (for the insect is infected in all

Fig. 1978. MILDEW IN SILKWORMS. (*Highly magnified.*)

stages) are sources of contagion unless immediately destroyed. This disease is called *muscardine* in France, *calcinetto* in Italy; the French name arises from the resemblance of the diseased caterpillar to a mealy kind of sugar-plum made in Provence, and sold by the name of muscardine; the Italian name also refers to the chalky or mealy surface of the skin. Various fumigations and washes have been tried, in order to purify infected nurseries, and to preserve others from the ravages of this malady: a solution of blue vitriol (sulphate of copper) applied to the wood-work, frames, &c. of the nursery is of great use in destroying the seeds of the fungus, but nothing is so good a preservative as rigid attention to cleanliness and good ventilation.

The improved means, first employed in Italy, for preserving the health of these valuable insects, are due to Count Dandolo, who gave particular and scientific attention to the subject, and superseded many an absurd custom in the rearing of silkworms. According to his method wicker shelves are arranged in a room at convenient distances, and are lined with paper, on which the worms are placed. Such worms only are placed together as have been hatched at the same time, the space allowed them being, for each ounce of eggs, 8 square feet during the first age, 15 feet for the second age, 35 feet for the third age, 82½ feet for the fourth, and about 200 feet for the fifth age. The mulberry-leaves are chopped in order to present a large number of fresh-cut edges to the young insect. Four meals a-day, as a regular rule, and luncheons between when the worms are particularly voracious, is the liberal allowance for their subsistence. The temperature at which silkworms are healthiest appears to be from 68° to 75°, though they are able to bear a much higher temperature. Alternations of heat and cold are exceedingly injurious to them.

When the silkworms are about to spin they are provided with little bushes of broom, heath, or other flexible substance, which are arranged upright between the shelves, their tops being bent into an arched form by the shelf above. The bushes are spread out like fans, to allow plenty of space for the cocoons; for if crowded, the worms are apt to form double cocoons, two working together, and these are worth only half the price of single cocoons. Specimens of these bushes, laden with cocoons, appeared in the Great Exhibition, like diminutive trees bearing golden fruit. There were also illustrations in abundance of the advanced state of silk culture in France, and of the success of a series of systematic attempts which have been made in that country to improve the breed of silkworms, and to lessen their liability to disease. The *Central Society of Sericiculture of France* exhibited beautiful specimens of silk, remarkably pure in colour, strong, and lustrous. In the department of the Drôme, where the culture is so extensive that upwards of 3,000,000 of mulberry-trees are required to supply the food of the myriads of worms, the method of managing the insects is slightly different from that which we have described. Instead of wicker shelves lined with paper, large bamboo-like rushes which grow on the banks of the Rhone, are cut down, split open, and attached together so as to form long cane beds about 2½ feet broad, called *claies*. These are arranged one above another on a rude framework erected throughout the chamber, spaces being left at intervals as passages for the attendants to traverse. The worms, as soon as they are hatched, are strewed among the *claies*, and the mulberry leaves at the proper moment scattered over and amongst them. The attendants make use of a short ladder to ascend to the higher *claies*. In other establishments the *claies* are arranged so as to hang from the circumference of large wheels placed at each end of the apartment: by turning these wheels the ranges of shelves rise and fall, and are transferred from side to side at the pleasure of the attendant.

The original improver of silkworm management, Count Dandolo, has written a volume on the subject, which has been translated into English, and published under the auspices of a society called the British, Irish, and Colonial Silk Company. The labours of this Company were the last, on an extensive scale, of a series of attempts made at various times to rear the silkworm in these dominions. It was thought that the introduction into Ireland of an easy and profitable employment of this description would be of great advantage to the peasantry of that country. Eighty acres of land were purchased near Michelstown in the county of Cork, and planted with nearly 400,000 white mulberry-trees, which thrived admirably. A small building was erected for rearing silkworms, and in spite of the moist and variable climate there would have been every prospect of success but for the ignorance and awkwardness of the peasantry, who had never been accustomed to any employment which required so much attention, and who failed in bestowing on the insects the care necessary to ensure success. A similar experiment was tried by the Company in England on a smaller scale. Upwards of 70,000 mulberry-trees were planted near Slough, and prospered there. But after some experience, the Company renounced the attempt to rear the silkworm in

the United Kingdom, and transferred the whole of their establishment to Malta. The unskilfulness of the labourers was also the cause that in America, as well as in Great Britain, the rearing of silkworms proved a failure. That it is not impossible to cultivate them in cold countries is proved by the fact that in Sweden, and also in Russia, the culture of the mulberry and the production of silk is carried on to a considerable extent. The high price of labour in this country presents an additional obstacle to the success of such an undertaking. Favourable results, however, have been obtained within the last 15 years, at Newlands, in Hampshire, through the energy and skill of a lady, Mrs. Whitby, who has planted various sorts of mulberry-trees, and proved that the dwarf Philippines are the most advantageous. With these trees, and a supply of eggs of the large Italian silkworm, she obtains silk equal in proportionate quantity and quality to that of Italy and France. Mrs. Whitby has presented to the Queen 20 yards of rich and brilliant damask, manufactured from silk raised at Newlands.

British India possesses the climate and the abundance of labour favourable to this undertaking: accordingly, we find the culture of the silkworm spreading and improving in that country. In Bengal there are 8 or 10 principal factories or *filatures*, each employing from 3,000 to 10,000 persons, and the results of the Great Exhibition prove the fine quality of the silk obtained.

The manufacturing treatment of the silk, when the labours of the silkworm are over, is as follows:—When the crop of cocoons is complete it is gathered from the bushes, and about one-sixtieth part is set aside for the production of eggs, the finest cocoons as to web and colour being selected for this purpose. A difference of weight generally determines which are the cocoons of male, and which of female insects: the latter are heavier and rounder than the former. The cocoons intended to produce eggs are preserved in a very dry room, and in about 10 days they lose in weight to the amount of $7\frac{1}{2}$ per cent.

The main crop of cocoons is next sorted into 9 qualities, known in the factories as—1, *Good cocoons*, which are strong, firm, almost equally round at both ends, not very large, but free from spots. 2. *Calcined cocoons*, in which the worm has died *after* having completed its work, and is reduced to a powdery substance. 3. *Cocalons*, which are larger and less compact than good cocoons. 4. *Choquettes*, cocoons in which the worm has died *before* finishing its work. 5. *Dupion*, or double cocoons, difficult to unwind, and often kept for seed. 6. *Soufflons*, cocoons of so loose and soft a texture that they cannot be unwound. 7. *Pointed cocoons*, in which one end rises in a point, which breaks off after a little silk has been unwound, and so spoils the thread. 8. *Perforated cocoons*, from which the moth has escaped. 9. *Bad choquettes*, in which the silk is spotted, rotten, and blackish in colour. The vitality of the chrysalis is destroyed previously to unwinding the cocoons: this is done either by exposure to the sun, or by artificial heat, such as that of an oven after the bread is withdrawn. The floss silk is removed from the cocoon by opening it at one end and slipping out the cocoon. In reeling it is necessary to use cocoons of one quality, as different qualities require different treatment.

The natural gum of the cocoons is softened by immersion in warm water, kept at the proper temperature by a charcoal fire, or by a steam pipe. After they have remained in it for a few minutes, the reeler (generally a woman) gently stirs up or brushes the cocoons with a short birch-rod, and to this the loose threads of the cocoons adhere, and are thus drawn out of the water. They are then taken 4 or 5 together, twisted with the fingers into one thread (as many as 30 can be wound together) and passed through a metal loop, which rubs off dirt and impurities; it then passes on to the reel, which has a slight lateral motion, so that the thread of one revolution does not overlay the other. If it were allowed to do so, the threads would be glued together before the gum had time to harden by exposure to the air. When any single thread breaks or comes to an end, its place is supplied by a new one, that the united thread may be of equal thickness throughout. The new thread is merely laid on, and adheres to the rest by its native gum, and as the filaments are finer near their termination than at the commencement, it is necessary to add other cocoons before the first set is quite exhausted. The cocoons are not entirely wound off, but the husk containing the chrysalis is used, together with the floss silk, under the name of *waste*. Improved methods of reeling are introduced from time to time, but they are on the same principle as the above. The length of filament yielded by a single cocoon is 300 yards, though some have yielded upwards of 600 yards. Eleven or twelve pounds of cocoons yield one pound of silk, from 200 to 250

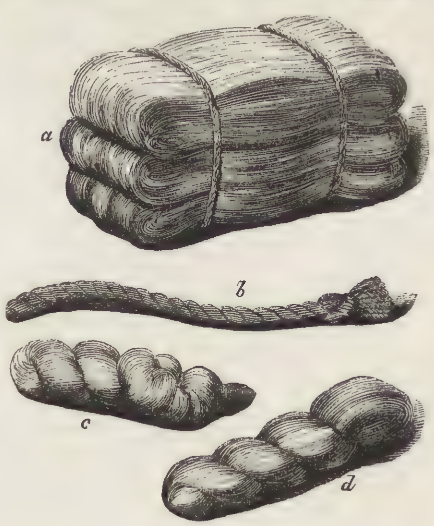


Fig. 1979.

a. BOOK OF SILK FROM CHINA. *b.* SLIP FROM BENGAL. *c.d.* HANKS FROM ITALY.

cocoons going to the pound weight: thus about 2,817 cocoons are included in that quantity. The reeled silk is made up into hanks for sale and use. The

form and contents as well as the quality of these hanks differ according to the quarter whence they are received, as will be seen by the figures.

The operations to which raw silk is subjected in order to prepare it for weaving or other purposes, consist chiefly of *winding*, *cleaning*, *spinning*, *doubling*, *throwing* and *reeling*. When the silk is merely wound and cleaned it is called *dumb singles*, and is used in that state for weaving into Bandana handkerchiefs; and, when *bleached*, for gauze, and similar fabrics. If the silk is wound, cleaned and thrown, it is known as *thrown singles*, and is used for ribbons and common silks. If wound, cleaned, doubled, and thrown, and twisted in one direction, it is called *tram*, and is used for the woof or shoot of Gros de Naples, velvets and flowered silks. If wound, cleaned, spun, doubled and thrown so as to resemble the strand of a rope, it is called *organzine*, and is strong enough to be used for warp. The natural gum of the silk is for some purposes allowed to remain, in which case the silk is termed *hard;* but if this stiffening gum is removed by *scouring*, it is termed *soft*.

In the first operation, that of *winding* the silk upon bobbins, each hank is extended upon a light, six-sided reel, called a *swift*. A number of these swifts are arranged side by side upon an axis on either side of a frame, as shown in Fig. 1980. Above the swifts

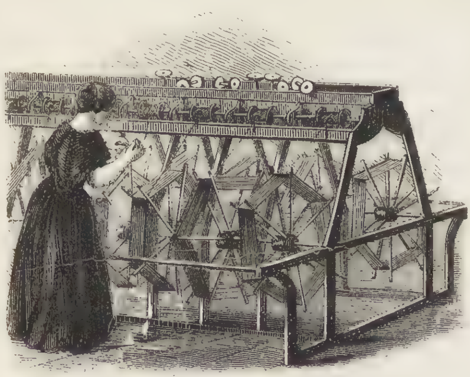


Fig. 1980. WINDING.

are the bobbins similarly arranged, one bobbin for each swift. The bobbins being connected with the swifts by means of the silken filament, are set in motion, thereby causing the swifts to turn round and deliver the silk. The hanks vary in size, and as the dimensions of the swifts require also to be varied to suit the hanks, the swifts which are made of laths of lancewood are arranged in pairs upon a central nave: the outer extremities of each pair are rather further apart than the inner ends, and are connected together by a band of small cord on which the hank of silk rests, so that by slipping the band nearer to or further from the centre, the size of the swift can be adapted to the dimensions of the hank. In putting on the hank the swift must be balanced, because if one side were heavier than another, it would in turning, by its sudden fall, snap the filament. The swifts turn freely in their supports, but friction is produced by hanging on the nave a small hoop to which weights are hung; this prevents the swifts from giving off the silk faster than it can be taken up by the bobbins. In order to distribute the filaments equally over the bobbins, each filament is passed through a small glass ring or eye attached to a horizontal bar which has a lateral traverse. The filament is thus wound in a spiral or oblique direction, which prevents the lateral adhesion of the filament, and allows its end to be readily found when it breaks. The winding machine requires constant attendance, in order to put on the hanks, exchange the bobbins, and join the ends of threads broken in winding. Motion is given to the bobbins by means of a friction roller, so that any one bobbin can be removed without stopping the other bobbins.

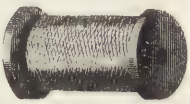


Fig. 1981.

The bobbins having been thus filled at the winding frame are removed to the *cleaning* or *picking machine*, where being fixed horizontally on plain spindles, each thread is carried from the bobbin over a glass or iron guide-rod, and then drawn through a brush or cleaner for the purpose of separating loose dirt; but in order to get rid of knots and irregularities, the cleaner consists of a bar of metal containing a small notch or hole capable of adjustment to a certain size. The filament is dragged from its bobbin through the cleaner to other bobbins, and should a knot or other irregularity occur which prevents the filament from passing through the hole, the plate of metal is depressed and the bobbin is lifted off the friction roller from which it receives motion, and this stoppage being noticed by the attendant, she picks out the mote or removes the knot, so as to allow it to pass through the cleaner, and then sets the bobbin in motion as before.

The cleaned filaments of silk are next twisted by means of the machinery employed in spinning cotton. Hence the twisting of a continuous filament is called

Fig. 1982. SPINNING.

spinning, although it does not resemble the twisting together of the short fibres of cotton, flax, or wool, to which the term is more properly applied. The bobbins of cleaned silk are mounted on a horizontal

axis, and the twisting is effected by passing the filament to other bobbins placed on vertical axes or spindles furnished with flyers, through the eyes of which the filaments are passed. While the horizontal bobbins deliver the filaments at a certain rate, the flyers rotate at a quicker rate, and thus put twist into the filaments, and the twist is hard or close in proportion to the velocity of the flyer.

In the process of *doubling*, a number of filaments are combined into one cord, the strength and durability of which are thus greatly increased. The thick cord used for making purses often consists of 30 threads laid side by side and twisted. Doubling is performed by a woman at a spinning wheel, the bobbins of thread to be doubled being mounted in a small frame. She first collects the loose ends from these bobbins, unites them into one, passes them through a kind of loop or jack, and attaches them to a bobbin which is set in motion by the wheel, which thus unwinds the threads from the bobbins in the frame, and lays them side by side on the bobbin attached to the wheel. When a sufficient number of bobbins are filled the parallel threads are transferred from them to a horizontal reel, and the ends are carried through the eye or loop of a rotating flyer, by the rotation of which the several threads are twisted or doubled together into a kind of rope. This operation is called *throwing*, a term which is sometimes

Fig. 1983 DOUBLING, OR THROWING.

applied to the whole class of operations by which silk is prepared for the weaver, &c. The term appears to be derived from the rope-maker who *throws* twist into his rope. In spinning or doubling, the direction of the twist varies according to the uses to which the thread is to be applied. In spinning single filaments the twist is to the right; for tram the spinning is omitted; after winding, the threads are doubled, and then twisted to the right: for organzine, the thread after being wound is twisted to the left, then doubled and twisted to the right. These variations modify the texture of the threads, and adapt them to various woven fabrics.

The doubling frame contains a contrivance for stopping the bobbin, should any one of the threads break. Suppose 2 threads are to be doubled or twisted together, each thread is passed through an eye in a bent wire, which it supports, as shown in Fig. 1984; so that should one thread break, the wire falls down on a lever which it depresses, and its opposite end acts as a sort of catch or paul to a ratchet-wheel attached to the end of the bobbin, thus stopping its motion until the attendant has mended the broken thread.

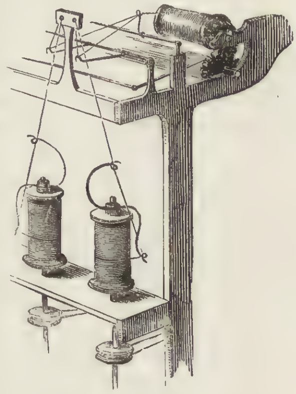


Fig. 1984.

Some of the heavier descriptions of silk thread, such as sewing, or fringing thread, are prepared by means of a *throstle frame*, similar in construction to that described under COTTON, Fig. 661. In this, as in the other cases above noticed, the twisting of the thread is set or made permanent by exposure to steam, the reels being enclosed for the purpose in a steam chest. The silk may be sent to the dyer either in the hard or the soft state. If in the latter, it is deprived of its gum by boiling it in soap and water for 3 or 4 hours, about one-fourth of the weight of the silk being lost in the process, but this loss is more or less compensated by the weight of the dye stuff, which sometimes amounts to 12½ per cent. This is of importance, as the manufacturer estimates the value of his goods by weight. Silk for ribbons, and some other descriptions of silk goods, are not boiled.

The silk after leaving the throwing mill is ready for weaving into various fabrics either at the common loom or at the jacquard loom; it also forms yarn or thread for hosiery and gloves, and also sewing or knitting silk. See WEAVING.

The floss silk and the refuse of the throwing process are worked into yarns for coarser fabrics, such as shawls and cheap Bandanas. The waste is sent to the spinner in small balls, which are sorted into parcels according to their quality. The filaments are next disentangled by a process of heckling, and they are laid parallel at the *filling engine*, where the silk, while being passed between feeding rollers, is subjected to the action of a series of moving combs. The next machine is the *drawing frame*, in which the filaments are held firmly in their place by one end, and the combs travel over their surface, and remove all impurities and short fibres. The latter in their turn are also dressed, and what remains in the combs is used for stuffing cushions and similar purposes. The parallel filaments are next cut into lengths of about an inch and a quarter by a *cutting-engine*, which acts much like a chaff-cutting machine. These lengths are then acted on by a *scutcher*, which converts them into fine down, which is put into bags and boiled for an hour or two in soap and water for the purpose of washing out the gum; it is next boiled in pure water to get rid of impurities, and is then submitted to

strong pressure in a Bramah press. It is next dried and again passed through the scutching machine. It is lastly carded and formed into yarn by processes similar to those described under COTTON. The spinning of waste silk has, however, of late years undergone several important improvements, by which the operations of cutting, carding, and scutching have been superseded, the uncut filament being drawn into a sliver by a modification of the gill used in the preparation of FLAX.

SILKWORM GUT. This substance is prepared for the angler as follows:—A number of the finest silkworms are selected when they are about to spin: they are killed by being immersed in strong vinegar, in which they are left for 12 hours closely covered up: should the weather be cool they may be left in the vinegar 2 or 3 hours longer. When removed therefrom, and pulled asunder, two transparent yellow-green cords will be observed: this is the silkworm gut: the other portion of the entrails are of a dark-green colour. If the gut be soft, or break by stretching, that is an indication that the worm has been taken out of the vinegar too soon. When the gut is fit for drawing out, one end is to be dipped into the vinegar, and the other to be gently stretched to the required length, and it must be kept extended on a thin piece of board by inserting its extremities into slits in the end of the wood, or fastening them to pins, and in this state it is placed in the sun to dry.

SILVER (Ag. 108), a metallic element known to the ancients, and mentioned in the book of Job. It is the whitest of all the metals, and capable of receiving a lustre which is scarcely inferior to that of polished steel. In its polished state it reflects more light and heat than any other metal, so that it has a very low radiating power for heat, and hence a silver vessel retains the heat of the liquid contained in it longer than a vessel of any other metal. The preference given to a silver pot for making tea is founded on correct observation: a black earthenware vessel is such a powerful radiator of heat, that a hot liquid contained in it rapidly declines in temperature, and if used for making tea the temperature of the boiling water soon falls below the point required for making the infusion. Silver ranks next to gold in ductility and malleability. Its density is 10·47: it is harder than gold and softer than copper, and, when pure, it is so soft as to be cut by a knife: the addition of a small quantity of copper increases its hardness: it fuses at a full-red heat, corresponding to 1,873° Fahr. Exposed to the heat of a blast furnace, silver throws off metallic vapours, and when fused between the charcoal electrodes of a powerful voltaic battery it is readily volatilized. When fused in considerable quantity, the crust allowed to cool, and the liquid portion run off, as explained under BISMUTH, Fig. 136, cubic and octahedral crystals of silver may be obtained. When fused in open vessels it absorbs oxygen, in some cases as much as 22 times its own bulk; and in solidifying it expels the gas, probably producing that kind of metallic vegetation which takes place on the surface of silver buttons when suddenly cooled on the cupel. When heated to redness in contact with porcelain or glass, the absorbed oxygen forms an oxide of the metal which, combining with the silica, produces a yellow enamel. At ordinary temperatures silver is not acted on by oxygen, but it is tarnished if exposed to an atmosphere containing very minute portions of sulphuretted hydrogen-gas, which is readily decomposed by silver. The caustic alkalies do not act on silver even at a red-heat, and hence the value of silver crucibles when substances are to be acted on by caustic potash. Oxide of silver is reduced by heat alone. Hydrochloric and sulphuric acids do not readily act on silver, but nitric acid attacks it with great facility. Chlorine, iodine, and bromine readily act on silver, as was noticed under PHOTOGRAPHY.

Silver may be obtained pure by dissolving a piece of money or of plate (which always contains copper) in nitric acid, and adding thereto a solution of common salt: this throws down the silver in the form of an insoluble chloride, while the other metals remain in solution. 100 parts of this chloride are, when separated and dried, mixed with 70 parts of chalk and 4 or 5 of carbon, and this mixture is introduced into a crucible, and raised to a white heat. Carbonic oxide is disengaged, and chloride of calcium and metallic silver remain in the crucible.

There are 3 oxides of silver, viz. the suboxide, Ag_2O, the protoxide, AgO, and the binoxide, AgO_2; but of these the protoxide only forms permanent and definite saline combinations. This oxide may be formed by adding caustic potash to a solution of nitrate of silver: the pale-brown precipitate thus formed is protoxide of silver. Ammonia dissolves it freely, and pure water takes up a small portion, forming an alkaline solution. The protoxide of silver neutralizes acids completely, and forms salts which are mostly colourless. It is decomposed at a red heat, oxygen being evolved and spongy metallic silver being left: it is also partially decomposed by solar light.

Perhaps the most important salt of silver is the *nitrate*, AgO,NO_5. It is prepared by dissolving silver in nitric acid, and evaporating the solution to dryness, or until it is sufficiently concentrated to crystallize on cooling. The crystals are colourless, transparent, anhydrous tables, soluble in an equal weight of cold, and in half their weight of boiling water: they are also soluble in alcohol. When heated in a silver crucible they fuse like nitre, and like that substance are cast into the form of cylindrical sticks, [see POTASSIUM, Fig. 1666,] forming the *lunar caustic* of the surgeon. This salt blackens by exposure to light, especially if organic matter be present; and it is even stated that, when the crystals are wrapped in paper, they are gradually reduced to the metallic state. Ivory, marble, and other bodies, may be stained black by soaking them in a solution of this salt and exposing them to the direct action of the sun's rays. On account of this property, nitrate of silver is the essential ingredient in the washes employed for dyeing the hair: it also enters into the composition of *indelible* ink for marking linen. The black stain is said to consist of metallic silver in a state of minute division,

but it may possibly be the suboxide. Cyanide of potassium will remove the black stain produced by any of these preparations of silver. Nitrate of silver is sometimes taken as a medicine, the effect of which is, to give to those parts of the body which are exposed to the light a leaden-grey or livid colour, in consequence of the discoloration of the *rete mucosum.* When a stick of phosphorus is introduced into a solution of nitrate of silver it soon becomes incrusted with arborescent crystals of the metal. A plate of copper also produces a brilliant precipitation of crystalline silver. The introduction of mercury into the solution of nitrate of silver produces a beautiful crystalline deposit of silver, known as the *arbor Dianæ.* To produce a good effect, the mercury should be already combined with $\frac{1}{8}$th its weight of silver.

Sulphate of silver, AgO,SO_3, may be formed by boiling together metallic silver and sulphuric acid, or by precipitating a concentrated solution of nitrate of silver by an alkaline sulphate. It is a white saline mass, easily fusible. It is soluble in 88 parts of boiling water, and separates for the most part in a crystalline form on cooling.

Small portions of gold may be separated from large quantities of silver by heating the alloy, finely granulated, in sulphuric acid: the gold remains as a black powder, and the sulphate of silver may be decomposed by the action of metallic copper: the silver is precipitated in a pulverulent state, which, with the assistance of borax or other flux, may be fused and cast into ingots.

Sulphate of silver forms a crystallizable compound with ammonia: it is soluble in water, and contains $AgO,\ SO_3+2NH_3$.

Hyposulphate of silver, $AgO,\ S_2O_5+HO$, is a crystallizable salt, permanent in the air. The *hyposulphite* is insoluble, but it combines with alkaline hyposulphites, forming soluble compounds of an intensely sweet taste.

Chloride of silver, $AgCl$, is produced by mingling together a soluble salt of silver and a soluble chloride. It forms a white, curdy precipitate, insoluble in water and nitric acid; but 1 part of this chloride is soluble in 200 parts of concentrated hydrochloric acid, and in about 600 parts when diluted with double its weight of water. Chloride of silver is fusible, and it cools into a greyish crystalline mass, which cuts like horn, and when found native is termed *horn-silver.* Pure chloride of silver either dry or wet, is slowly decomposed by light, and quickly if organic matter be present. It is also reduced if put into water with metallic zinc or iron. It is readily soluble in ammonia, and in a solution of cyanide of potassium. See Photography.

Iodide of silver, AgI, is a pale yellow insoluble precipitate formed by adding nitrate of silver to iodide of potassium: it is insoluble or nearly so in ammonia, differing in this respect from the silver salts in general. The *bromide* of silver resembles the chloride.

Fulminating silver. When precipitated oxide of silver is digested in ammonia, a black substance is produced which is dangerously explosive. It explodes under water when heated to 212°; it also explodes when moist by friction with a hard body, and when dry the touch of a feather or the vibration of the house occasioned by the rolling of a carriage in the street is sufficient to cause it to explode. There is a similar compound containing oxide of gold. "It is easy to understand the reason," says Fownes, "why these bodies are subject to such violent and sudden decomposition by the slightest cause, on the supposition that they contain an oxide of an easily reducible metal and ammonia; the attraction between the two constituents of the substance is very feeble, while that between the oxygen of the one and the hydrogen of the other is very powerful. The explosion is caused by the sudden evolution of nitrogen gas and vapour of water, the metal being set free."

There is a large demand for silver, not only for the purposes of coinage, but also for services of plate, for which it is admirably adapted, inasmuch as it is not attacked in the slightest degree by any of the substances used for food. The large demand for the metal thus occasioned is met by its comparative abundance in the native state or alloyed with various other metals; it is also found mineralized by the non-metallic elements, and also in combination with certain acids. It is also obtained in large quantities from lead ores, as noticed under Lead, and in the Introductory Essay, p. xcix. where Mr. Pattinson's method of separating silver from argentiferous galena is noticed.

Native silver accompanies the other ores of this metal, particularly the sulphuret and the chloride: it occurs either in the crystalline or the arborescent form. Native silver is also found in amorphous masses, one of the largest of which is preserved at the Museum of Copenhagen: it weighs about 500 lbs., and was procured from the mines of Konigsberg in Norway. Native silver is often found disseminated in ferruginous rocks, and in the district about Lake Superior it is found associated with malleable copper. A compound of silver and mercury, known as *native amalgam,* is also found in the form of thin compressed plates, and also in crystals.

Silver combines readily with sulphur, producing a grey crystallizable *sulphuret,* much more fusible and soft than silver. It may be obtained artificially by heating silver with sulphur. Its density varies from 6·8 to 7. The native sulphuret of silver or *vitreous silver ore* occurs in various forms, and when crystallized is in cubes, octahedra and dodecahedra. It is of a shining lead grey colour; its fracture is slightly conchoidal, inclining to vitreous. It is very fusible, and being one of the richest and most abundant of the ores of silver, it supplies a large proportion of the demand. It is found in Saxony, Bohemia, and Hungary, and is very abundant in the mines of Guanaxuato and Zacatecas in Mexico. It is often associated with the sulphurets of copper, iron, and antimony. *Brittle silver ore* is of an iron-grey colour inclining to black: it is very brittle: sp. gr. 6·2. A specimen from Freyberg contained silver 66·50, copper and arsenic 0·50, iron 5, antimony 10, sulphur 12.

Polybasite is another variety of brittle sulphuret of silver. *Antimonial silver* is a natural alloy of these two metals. *Encairite* is a silver ore containing copper and selenium.

One of the richest and most abundant ores of Chili is the *chloride*, where it is often accompanied by native silver. It is found in massive amorphous fragments associated with the sulphuret, and it also occurs in small cubical crystals disseminated in the ferruginous rock known by the name *pacos* and *colloradas*. The colour of this ore is white or yellowish white, and by exposure to the air it becomes violet. The fracture is vitreous and conchoidal: it is soft, and can be scratched by the nail. This ore is of somewhat rare occurrence in the mines of Europe. The *iodide* of silver also occurs native, as does also the *bromide:* the latter ore has been found in large quantities in the district of Plataros in Mexico, where it is called *plata verde*, from the colour imparted by the bromine.

A large proportion of the silver of commerce is extracted from ores which are too poor to allow of their being smelted or fused, even supposing fuel were abundant in the neighbourhood of the mines, which is not the case. Recourse is therefore had to the process of *amalgamation*, founded on the ready solubility of silver and many other metals in metallic mercury. The Saxon process as adopted at Freyberg differs somewhat from the American process. The argentiferous ores of Saxony consist of sulphurets of silver combined or mixed with sulphurets of arsenic, antimony, iron, zinc, &c. They should not contain more than 5 per cent. of lead, and 1 per cent. of copper, for these two metals disturb the process of amalgamation; they unite with mercury as readily as silver, and produce a very pasty amalgam. The ores from the different mines are so mixed, that a ton of ore contains from 75 to 80 ounces of silver: a certain proportion of sulphur is also required, and this is usually furnished by the iron pyrites, which on being roasted furnishes the sulphate and oxide of iron required for the subsequent process; or sulphate of iron may be added to the charge.

The ore is spread over a floor 40 feet long, and about 12 wide, and over the charge is sprinkled about 10 per cent. of common sea-salt: the whole is then well mixed together, and is divided into small parcels called *roast-posts*, each weighing from 3½ to 4½ cwts. Each post is roasted in a reverberatory furnace, in which the heat is very gradually raised: for the first 2 hours only a drying heat is used, the charge being constantly stirred: the heat is then raised sufficiently to ignite the sulphur and raise the ore to a red-heat. In about 4 hours the metals at this temperature become oxidized, and sulphurous acid gas is given off rapidly: the ore is prevented from agglutinating in masses by constant rabbling. The temperature is now raised, and vapours of chloride of iron and hydrochloric acid accompany the sulphurous acid. The hydrochloric acid arises from the decomposition of the chloride of iron by the action of oxygen and aqueous vapour. The last firing is continued about ¾ hour, until the charge ceases to evolve sulphurous acid, its object being to decompose the sea-salt by the metallic sulphates. The ore now increases in volume, and assumes a deep brown colour, and the roasting being complete the charge is raked out, and when cool is passed through fine sieves for the purpose of separating the powder from the agglutinated lumps. The latter are broken down, mixed with a fresh quantity of salt, and roasted again. The powder is ground to an impalpable state between heavy mill-stones, and when bolted and dressed, after the manner of preparing wheat-flour, it is ready for amalgamating.

The reactions which take place during the roasting are thus explained by Regnault:[1]—The sulphurets of iron and of copper disengage sulphurous acid gas, and are converted into oxides and sulphates. The sulphuret of silver, on being heated in contact with the sulphates of iron and copper, is converted into sulphate; the copper and the iron being oxidized, give off sulphurous acid. The sulphates of copper and of iron, together with the sea-salt, with which they are mixed, become fused even below a red-heat; and if the mixture contain sulphuret of silver, a further amount of sulphurous acid is evolved by the decomposition of the sulphuret produced by the reaction of its sulphur on the sulphuric acid of the sulphates; and sulphate of soda, chloride of silver, and chlorides of copper and of iron, are also formed. If these reactions take place in the presence of atmospheric air the iron is partly converted into sesquioxide, and a sesquichloride of that metal is also formed. The sulphurets of antimony and of arsenic are also oxidized, so that the roasted mineral may be regarded as composed of sulphate of soda, chloride of sodium, chlorides of manganese and of lead, sesquichloride of iron and subchloride of copper, earthy impurities and various metallic oxides.

The amalgamation of the prepared ore is conducted in wooden barrels B B, Fig. 1985, revolving on iron

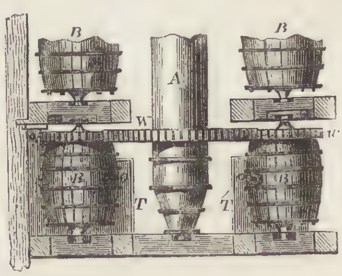


Fig. 1985.

axles attached to the ends. Each barrel is 2 feet 10 inches long, and 2 feet 8 inches in internal diameter: it is made of oak staves, and is strengthened by iron hoops and binders. A toothed wheel *w w'* is attached to one end, which engages another toothed wheel W mounted on an axle A, which is driven by water-power. Above each barrel is a wooden case C, Fig. 1986, into

(1) Cours Élémentaire de Chimie. Tome Troisième, 1849.—See also Phillips's Manual of Metallurgy, published, 1852, in the new edition of the Encyclopædia Metropolitana.

which the prepared mineral is thrown, and from this case proceeds a leather hose *l* for passing the powdered ore into the barrel, which is provided for the purpose with an opening *o*, which is plugged with an iron or wooden screw stopple during the revolution of the barrel. Above each barrel is also a vessel R, Fig. 1986, for containing the exact amount of water required for each charge, and below each barrel is a trough T for the reception of the charge when the amalgamation is complete. At the commencement,

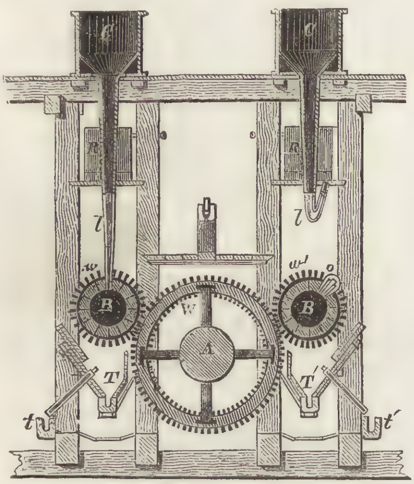


Fig. 1986.

3 cwt. of water are run into each barrel: then 10 cwt. of the powdered ore: to this are added from 78 to 100 lbs. of wrought-iron in fragments of about an inch square and $\frac{3}{8}$ths inch thick; and when this is dissolved a fresh quantity is added. The stopple being screwed in, the casks are thrown into gear with the revolving axis A, which rotates about 18 or 20 times per minute. In 2 hours the casks are thrown out of gear, and the charge examined: if it be found too firm it is diluted with a small quantity of water; if too liquid, more powdered ore is added. 5 cwt. of mercury are now poured into each cask, and the revolution is kept up for 16 or 18 hours, the rotations being from 20 to 25 per minute. During this time the charge is examined twice, and water or powdered ore are added as may be required. The addition of the mercury produces a rise in temperature: in winter it may be as much as 104° Fahr. After the lapse of 20 hours the amalgamation of the silver is usually complete: the barrels are filled up with water, and made to rotate 8 times per minute. This occasions the separation of the amalgam from the slimy matters with which it was mixed, and enables it to collect at the bottom of the tuns. The casks are now thrown out of gear, and the holes *o o* are placed over the troughs T T′. A small peg is removed from the stopple, and the liquid amalgam flows into the trough, and the moment any of the earthy matter begins to appear the hole is closely stopped. The amalgam is run off from the troughs T T by an iron tube into the gutters *t t*, which convey it to a receiver. The casks are then turned with the holes *o o* upwards, the stopples are removed, and the muddy residuum is discharged into a spout which conveys it to reservoirs placed at a lower level. The ore is found to be deprived of its silver to within about $5\frac{1}{2}$ oz. to the ton, and is often subjected to another amalgamation.

The whole of the above process, including 2 hours for discharging the casks, occupies about 24 hours. Every 5 tons of mineral require an expenditure of 15 lbs. of metallic iron and 2 lbs. $12\frac{3}{4}$ oz. of mercury. The action is as follows:—Before the introduction of the mercury the sesquichloride of iron in the ore is decomposed by the metallic iron, and converted into protochloride. If the mercury were at once introduced it would by its reaction on the prochloride of iron become partially converted into protochloride of mercury or calomel, and thus occasion loss; but by first allowing the metallic iron to act, a protochloride of iron is formed, and this has no action on metallic mercury. The chloride of silver of the roasted ore is held in solution by the chloride of sodium, and becoming reduced to the metallic state by agitation with the metallic iron, combines with the mercury in a liquid amalgam. The chlorides of lead and copper are decomposed at the same time as the chlorides of silver, and unite with the amalgam.

When the earthy matters are drawn off from the casks, the pieces of metallic iron are retained by a grating, and the slimes are first run into receivers and then into *pug-tubs*, where they are stirred up with water. These tubs have openings at different distances from the bottom, by which the muddy water is successively drawn off. A portion of amalgam collects at the bottom of the vessel, and this is added to that drawn off from the casks. This amalgam is filtered through close canvass bags, by which the liquid mercury is separated from the pasty amalgam. The latter is a mixture of 6 parts mercury and 1 part of an alloy containing 80 parts silver, and 20 of a mixture of copper, lead, bismuth, antimony, gold, nickel, zinc, and some other metals. This mixture is heated in a distillatory furnace, and the adhering mercury thus got rid of, while the non-volatile parts of the alloy are obtained in the solid form. The furnaces at Halsbrücke are well contrived for condensing the mercury. Beneath the furnaces are wooden drawers, *d d*, Figs. 1987, 1988, sliding in grooves, and supporting an open basin of cast-iron *i*; these themselves support a wrought-iron stand *s*, resting on iron feet *c* placed within them. This upright shaft passes through the centre of 5 cup-shaped iron plates, which are placed at distances of about 5 inches apart, and are destined to hold the amalgam which is to be operated on. Over this is lowered, by means of a crane and chain, a cast-iron bell-shaped dome D, supported by a wrought-iron framing and furnished with a loop. A sheet-iron door *r* is also employed for the purpose of closing up the front of the aperture, when the amalgam has been placed on the support, and the bell has been accurately deposited over it. "The total weight of the balls of amalgam in each furnace usually

amounts to about 3 cwt., and after the bell has been let down over it and the door closed, the basin is filled with water, and a fire, made with chips of firewood, is lighted on the plate, which has a hole in the centre, and accurately fits the sides of the bell in the

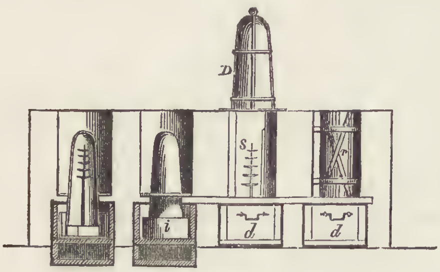


Fig. 1987.

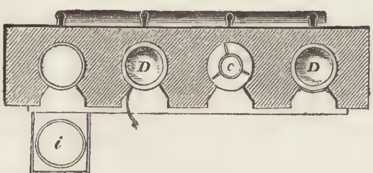


Fig. 1988.

part where it is situated. Before closing the door, it is thickly lined with fire-clay, and the apertures existing between it and the wall are afterwards securely luted up. When the wood has become well ignited, the space is gradually filled up with fuel, which consists at first of turf, and afterwards of charcoal. In this way the bell becomes red-hot, and the mercury which is sublimed, falls down, and is collected in the basin, which is constantly supplied with cold water, through pipes laid on for that purpose. At the end of 8 hours the operation is usually finished, and when no more globules of mercury are heard to drop into the water, the fire is allowed to go gradually out. When sufficiently cooled, the bell is removed by means of a crane, and the impure silver is taken from the shelves of the support. The mercury collected in the basin, is, after being drained and dried, sent back to the works to be again employed in amalgamation, while the impure silver is refined by fusion, and subsequent cupellation." The mercury dust is, from time to time, removed from the fume-flues and ground with the crucibles which have been used in refining: it is then sent to the amalgamation mill. The earthy residuum from the casks, on being subjected to a second treatment, yields about 4½ oz. of crude silver to the ton, which is mixed with that obtained from the first process. The liquor run off from the tanks in which the schlich is allowed to subside, contains sulphate of soda, common salt, and sulphate of iron, with other soluble salts, in small portions. The earthy deposits from the second amalgamation contain silver, but not enough to pay for a third working.[1]

(1) An account of the amalgamation of copper matts at Mansfeld, and the Mexican method of amalgamation, is given in Mr. Phillips's "Manual of Metallurgy."

The assay of silver ores and alloys by cupellation, is noticed under ASSAYING. The results obtained by this method not being perfectly accurate, the French Government in 1829 appointed a commission for inquiring into the subject, the result of which was the adoption of the liquid or humid method of assay, in which the standard of the alloy of silver and copper is determined by means of a solution of chloride of sodium, the strength of which has been accurately determined. The solution is so regulated as to strength, that a decilitre thereof will exactly precipitate 1 gramme of pure silver. In order to ascertain the composition of an alloy, 1 gramme thereof is dissolved in 5 or 6 grammes of nitric acid, and to this is added from a graduated apparatus, so much of the solution of common salt, until no further precipitate of the insoluble chloride of silver takes place. When the point of saturation is nearly attained, the bottle must be well shaken after the addition of each dose of the salt solution, in order that the liquor may become clear through the precipitation of the chloride of silver. The whole of the silver being thus thrown down, the exact quantity of the solution of common salt employed for the purpose is read off from the graduated scale, and this at once indicates the per centage of silver present.

When the composition of an alloy is known by approximation, as in the case of a silver coin or of a piece of plate, the humid method is not only very simple, but affords the most exact results. In such a case, two distinct solutions of common salt are used, the first of which, called the *normal solution*, is of such a strength, that 1 decilitre will precipitate 1 gramme of pure silver. The second, named the *decimal solution*, is only $\frac{1}{10}$th of the strength of the first, and is consequently of such a strength, that 1 litre of the solution will precipitate 1 gramme of pure silver.

Suppose, for example, a piece of silver money of the French coinage is to be examined, and which, in order to be of the legal standard, should contain $\frac{897}{1000}$ths of pure silver. Suppose the alloy to contain only $\frac{896}{1000}$ths of pure silver, whereby 1·116 gr. of the mixture would correspond to 1 gr. of pure silver. This quantity is therefore cut off the coin, accurately weighed, and put into a bottle which admits of being perfectly closed by a glass stopple, and it is dissolved in from 5 to 6 grammes of pure nitric acid. As soon as the solution is completely effected, 1 decilitre of the normal solution of salt is introduced. If the alloy be of the standard $\frac{896}{1000}$, the whole of the silver will be precipitated by the quantity of solution added, and the supernatant liquor will contain no traces of chloride of sodium in excess. But if the standard be higher than $\frac{896}{1000}$, a portion of silver will still remain in solution, and if it be below $\frac{896}{1000}$, the whole of the silver will have been completely precipitated, and the liquor will contain an excess of chloride of sodium. In order to ascertain which result has been produced, the bottle is carefully closed with its glass stopple, and briskly shaken, until the precipitate has subsided and the solution become clear. A cubic

centimetre of the decimal solution, capable of precipitating 0·001 gr. of pure silver, is introduced. If any silver remain in solution, the liquor becomes cloudy, and after being again shaken another centimetre of the decimal solution is added. If the liquor again becomes turbid, it is again well shaken, allowed to become clear, and a third centimetre of the decimal solution poured in, and so on, until no further cloudiness is produced by the addition of the decimal solution. Suppose that 5 of the cubic centimetres of the decimal solution have been introduced in succession, and have produced a precipitate in the liquor, while the addition of the sixth has not affected its transparency, it may be concluded that after the precipitation of 1 gramme of pure silver by the decilitre of the normal solution, the liquor still contained at least $\frac{4}{1000}$ths of a gramme of silver. But as the fifth cubic centimetre of the decimal solution produced a cloudiness and the sixth did not, it is evident that the liquor did not contain more than $\frac{5}{1000}$ths of a gramme of silver, and thus in adding $\frac{4\cdot5}{1000}$ths, the exact result is certainly attained within one half-thousandth of the truth. The standard of the alloy in question will thus be $896+4\frac{1}{2}=900\frac{1}{2}$ thousandths. If, on the contrary, the decimal solution produce no further precipitate in the solution of silver which has already received the decilitre of the normal liquid, the standard of the alloy is evidently below $\frac{896}{1000}$ths. Its exact composition is ascertained by means of a standard solution of silver in nitric acid, so adjusted that 1 litre of the liquor contains exactly 1 gramme of pure silver: this is called the *decimal solution of silver*. In using it, a cubic centimetre thereof is dropped from a pipette into the bottle containing the assay, and it occasions a precipitate of salt exactly corresponding to the same volume of the decimal solution of common salt which was added for the purpose of ascertaining if all the silver were precipitated. The liquor being made clear by agitation, another cubic centimetre of the silver solution is added. If cloudiness be produced, the bottle is again shaken, and a third measure of the solution introduced, and so on until the silver solution ceases to produce a precipitate. Suppose the first 5 cubic centimetres of the silver solution produced a precipitate, and that the sixth did not, it is probable that the whole of the fifth was not entirely decomposed, and it is usually stated that $4\frac{1}{2}$ cubic centimetres of the silver solution have decomposed the excess of the chloride of sodium left in the liquor after the addition of the decilitre of the normal solution. Hence we must subtract $4\frac{1}{2}$ thousandths from the presumed title of the alloy, the correct standard of which will be expressed by $896-4\frac{1}{2}=891\frac{1}{2}$ thousandths.

In places where numbers of assays of silver and copper alloys have to be made, the apparatus is so arranged as greatly to assist the operation. The normal solution is kept in a large vessel of sheet-copper, tinned on the inside, and supported on a shelf near the ceiling of the laboratory, as shown at V, Fig. 1989; and to prevent evaporation it is furnished with an immovable cover, through which passes a tube for the urpose of admitting air to supply the place of the solution drawn off. A gage *g* at the side shows, at a glance, the quantity of the saline solution contained in the vessel. From near the bottom of the vessel proceeds a tube *t* furnished with a stop-cock *c*. The

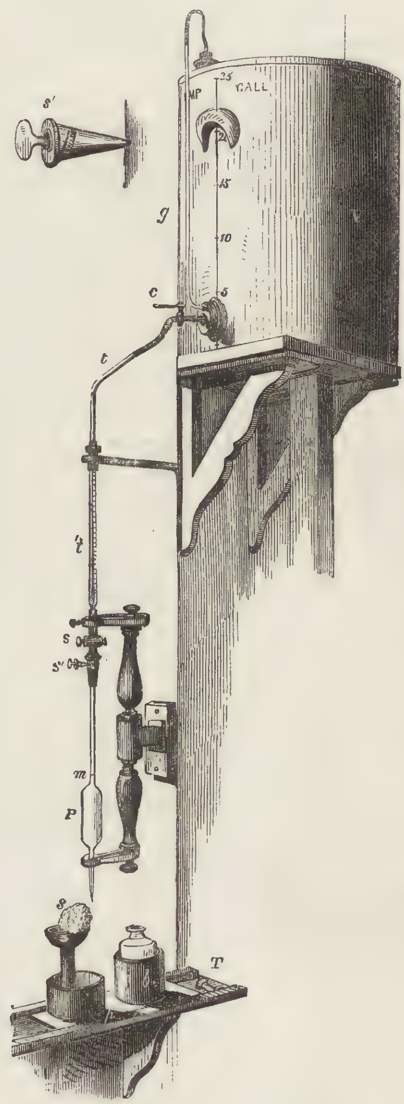


Fig. 1989. SALT APPARATUS.

pipette P contains exactly a decilitre of the saline solution, and it is connected with the tube *t* by another tube *t'* containing a thermometer. The metal connecting piece, by which the tube *t'* is fastened to the pipette, is furnished with 2 stop-cocks *s* and *s'*. In an assay the operator closes the extremity of the pipette with the forefinger of the left-hand, and with the right opens the stop-cocks *s s'*: the stop-cock *s'*, shown separately in Fig. 1989, is so constructed as to allow the air to escape in proportion as the solution enters the pipette. When this is filled a little above the mark *m*, the cocks *s s'* are closed, and the pipette remains charged with the solution after the

finger is removed. Below this apparatus is a sliding support T, in which is a case of copper *b* for supporting the bottle which contains the solution of the alloy in nitric acid, and close to it is a small stand containing a sponge *s* covered with linen and arranged at the exact height of the beak of the pipette. The operator slides the plate *p* in the grooves of the stand T, so that the sponge may be in contact with the end of the pipette, and by carefully admitting air through the stop-cock *s′*, the solution is allowed to descend until it reaches the mark *m* scratched on the glass. The sponge removes the last drop of the solution which would otherwise be attached to the beak, and as the sponge becomes saturated the solution passes down the hollow stem of *s* into the cylindrical vessel beneath. The slide is now drawn forward until it is stopped by a peg, when the neck of the bottle *b* will be exactly under the beak of the pipette: the stop-cock *s′* is now opened, and the solution flows into the bottle. When a number of alloys are to be assayed at the same time, they are contained in a number of bottles arranged in a metal frame something like a cruet-stand, Fig. 1990, and marked with numbers; and after the acid has been added, the stand is placed in hot water, in order that the heat may promote the solution. By the side of each bottle is a small cup for holding the stopple. When the solution is completed the nitrous fumes are removed from the bottles by blowing into them with a glass tube, and a decilitre of the normal solution of salt is added to each, as already noticed. The bottles are afterwards placed in another metal frame F, Fig. 1991, suspended from the extremity of a steel spring *s*, and steadied below by an elastic spring I R of vulcanized india-rubber. The bottles being closed by their respective stopples and secured in their several compartments by a kind of collar, Fig. 1992,

Fig. 1990.

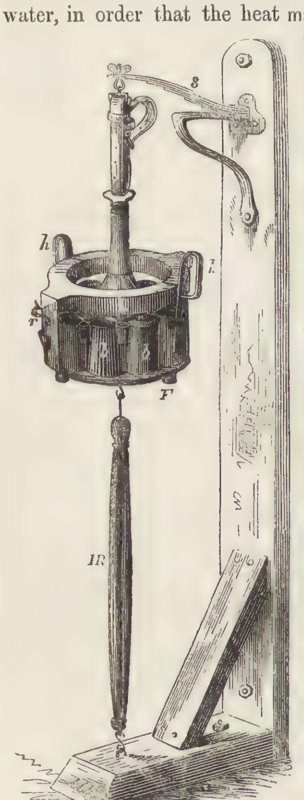


Fig. 1991. SHAKING APPARATUS.

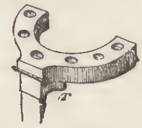


Fig. 1992.

which, when thrown up, is supported by a rest *r*, are well shaken by an assistant, who takes hold of the handles *h h*, and moves the whole apparatus briskly up and down for a few minutes. When the liquors have become clear the bottles are removed from this frame to a black table furnished with divisions numbered to correspond with the numbers on the bottles. The decimal solution, which is contained in a bottle with a pipette passing through its stopple, is now employed for determining the exact standard of the various assays. The pipette has a line drawn on its surface, graduated so as to allow the operator to measure out 1 cubic centimetre of the solution. For this purpose the point of the forefinger closes over the upper extremity of the tube, which is then removed from the bottle, and by the careful admission of air at the top, the liquid is allowed to drop until it has fallen to the level of the line marked upon the glass. The top of the tube is again closely stopped by the finger, and the cubic centimetre of the solution is transferred to the first bottle of the series, into which it is allowed to flow by removing the finger. Each of the other assays receives the same quantity of the solution. The bottles are then examined, and a chalk mark is made on the black table before those bottles which exhibit precipitates. These are briskly shaken at the shaking apparatus; returned to the black table, and another dose of the decimal solution is added to each bottle, in which a precipitate was obtained by the last operation. In this way the several bottles which give no precipitate are discovered, and the number of chalk-marks before each shows the number of cubic centimetres of the decimal solution added to each assay. Half a centimetre is deducted from each to allow for the loss on the last addition, a portion only of which has probably been decomposed.

The normal solution of common salt is prepared at the temperature of 15° Cent. But as the density of the solution varies with the temperature of the air, it is necessary to apply certain corrections when the assays are made at temperature above or below 15° C. For this purpose the thermometer contained in the tube *t′*, Fig. 1989, should be consulted, and the corrections read off from tables prepared for the purpose; but in order to prevent error, the assayer usually makes an experiment every morning on the saline solution with 1 gramme of pure silver, and the indications thus afforded enable him to ascertain the exact constitution of the solution, and to correct it accordingly.

The standard solution of chloride of sodium is made by dissolving 500 grammes of common salt in 4 litres of water, and filtering. The additional quantity of water required for the normal solution, supposing the salt to be pure, is now added, and the solution is carefully adjusted to the proper strength by testing it with the solution of pure silver in nitric acid. The decimal solution is prepared by pouring a cubic decilitre of the normal solution into a bottle of the exact capacity of a litre, and filling it up with pure distilled water. The decimal solution of silver

is prepared by dissolving 1 gramme of pure silver in nitric acid, and to this distilled water is added to make up an exact litre of the liquid.

If the alloy operated on contain mercury or lead, the results of the humid assay are not exact, since these metals are precipitated with the silver and decompose a portion of the normal solution. The presence of mercury is detected by the difficulty of obtaining a transparent solution by agitation. Such being the case the assay is not to be relied on. The assay of alloys containing mercury may, however, be conducted by the humid process by adding a solution of acetate of soda to the nitric acid liquor containing the silver previously to the introduction of the normal solution: the acetate prevents the formation of chloride of mercury.

Professor Graham, of University College, London, and Professor Miller, of King's College, conduct the silver assays for the Royal Mint by the humid process. Professor Graham adopts the French system of weights and measures above described. Professor Miller has modified it so as to suit English weights and measures. The following is a brief outline of the process as conducted by that gentleman, and kindly communicated by him:[1]—10 grains of the alloy to be assayed are accurately weighed, and dissolved in 120 grains of pure nitric acid. The standard solution of salt is so regulated that 1000 grains thereof will exactly precipitate 1 grain of pure silver. Now, taking the standard of English silver at 925 silver and 75 copper, care is taken to keep an excess of silver in the solution, for if salt be in excess, however small, no amount of shaking will get it clear. Accordingly the pipette P, Fig. 1989, is charged with the standard solution to the mark *m*, which is equivalent to 923 grains, a quantity which is capable of precipitating 923 grains of pure silver: the liquor is agitated for about a minute, and then allowed to settle. 10 grains of the decimal solution, capable of precipitating $\frac{1}{100}$th of a grain of silver, are now added: if a cloud be produced a chalk mark is made against the bottle. The liquor is agitated for a minute: a second dose of the decimal solution is added, and if no precipitate is produced, it is thus shown that of the 10 grains of the alloy 9·23½ grains consist of pure silver, the rest being alloy; thus showing a result a little below the standard. The standard solution of silver is formed by dissolving 10 grains of pure silver in pure nitric acid, and diluting it so that 1000 grains thereof shall contain 1 grain of silver.

The alloy of silver and copper used for coin and for the manufacture of silver-plate, is adjusted by the legislature of the country. In this country the same alloy is used for both purposes: the standard silver of England consists of 111 parts of silver and 9 of copper; or in 1,000 parts, 925 of silver, and 75 of copper, as already noticed. In order to prevent fraud, all vessels of silver are required to be stamped by the Goldsmith's Company, who are authorized to search the shops of silversmiths and seize articles which do not bear the hall-mark of the company. The company makes a charge of 1*s*. 6*d*. per ounce on the weight of the object for the assay thereof and the impression of the stamp. The larger portion of this sum is paid over to Government as a tax, a small deduction being made for the assay. In France there are three different standards. The alloy used for the silver coinage is composed of 9 parts silver and 1 of copper; for plate, 9½ parts silver to ½ a part of copper; and for small articles of silver, such as those used for ornaments, the alloy consists of 8 parts silver to 2 of copper. The silver coins of the ancients and many Oriental silver coins are nearly pure: they contain only traces of copper and of gold.

(1) We have also to thank Professor Miller for allowing us to copy his apparatus, as shown in Figs. 1989 to 1992.

The addition of a small proportion of copper increases the hardness of silver in a remarkable degree, without greatly diminishing its whiteness. An alloy of 7 parts silver and 1 of copper has a decidedly white colour, although less pure than that of virgin silver. Even with equal weights of the 2 metals the alloy is white. The maximum of hardness is obtained when the copper amounts to $\frac{1}{5}$th of the silver. Articles formed of alloyed silver are subjected to a process called *whitening*, which has the effect of removing the baser metal from the surface. The article to be whitened is heated nearly to redness, and plunged, while still hot, into water acidulated with nitric or sulphuric acid, by which means the oxide of copper formed by heating the surface in contact with air is immediately removed. The matted appearance of the surface, called *blanched* or *dead* silver, due to the isolation of the particles of silver, is removed by burnishing. The blanks for coin undergo the process of whitening, whence the blanched appearance of new coin, and the darker appearance of the projecting portions, occasioned by wear in consequence of the alloy appearing beneath the pure surface. Articles of plate are also deadened or matted by boiling them in bisulphate of potash, which acts in the same way as sulphuric acid.

Silver solder consists of 667 parts of silver, 233 of copper, and 100 of zinc. Silver is largely used for plating the surfaces of articles made of inferior metals, for which purpose some of the methods described under PLATING and ELECTRO-METALLURGY may be adopted, or the silver may be applied to the surface of the object in the form of an amalgam, the mercury being driven off by heat. By a process of this kind buttons are gilt. [See BUTTON.] For silvering brass, a mixture of chloride of silver, chalk and pearlash is used: the metal is made chemically clean, and the mixture moistened with water is rubbed on the surface.

SIMPLE BODIES. A list of elementary bodies with their atomic weights and symbols is given under ATOMIC THEORY.

SINGEING. See BLEACHING, Fig. 138.

SIPHON (σίφων, a tube), a bent tube, one leg or branch of which is longer than the other, used in raising fluids or emptying casks, &c. In Fig. 1993, the siphon A B C is represented with its shorter leg A B, immersed in the liquid which is to be transferred

from the cask A to the measure E. When the shorter leg is immersed in A the air is removed from the tube by applying the lips to the extremity C of the longer limb, and sucking out the air, in which case the atmospheric pressure exerted on the surface of the liquid in A, forces the liquid up the short branch A B, towards the highest point B; and if this point be not at a greater height than about 32 feet, if water be contained in A, and not more than 30 inches if it be

Fig. 1993.

mercury, the fluid will pass beyond the highest point B, and fill the whole of the tube to C. The vessel E may then be placed under the open end C, and the whole of the liquid in A situated above the end A will be transferred into E. The use of the siphon is more convenient by attaching a stop-cock *c* to the end of the longer branch, and placing on the same branch a small bent tube *c t*, communicating with the tube above the stop-cock. When the end of the shorter limb is placed in the liquid to be drawn off, the stop-cock *c* is closed, and the mouth being applied at *t* the air is readily sucked out. In some cases the siphon may be held with its ends upwards, filled with liquid, the ends closed, turned downwards, and the shorter immersed in the liquid to be drawn off.

The reason why one limb of the siphon is longer than the other is that the atmospheric pressure acts as forcibly at one extremity of the siphon as at the other. If when the liquid is raised to the highest point B, the mouth be withdrawn from C, the liquid will fall back into the vessel A. Such also will be the case if the liquid get no further than F, (which is the level of the liquid in A,) because at that point the upward pressure of the atmosphere prevails over the downward pressure of the liquid; but beyond that point in the direction F C the downward pressure of the liquid prevails over the upward pressure of the atmosphere, and the liquid will flow out. Thus the motion of the fluid is, as Mr. Webster remarks, similar to the motion of a chain hanging over a pulley. If the 2 parts of the chain be equal, the fluid remains at rest; and if one end be longer than the other it moves in the direction of the longer end. Fresh links, so to speak, are added continuously to the fluid chain by the atmospheric pressure on the surface of the fluid, so that the chain being continuous, the motion is continuous also, and does not cease until one portion of the chain becomes equal to or less than the other.

SIZE is made of thin glue [see GELATINE], and for finer work, it is prepared by boiling white leather or parchment cuttings in water for a few hours, or until a thin jelly-like substance is formed.

SKEW-BRIDGE. Square arches, or those which stand at right angles to their abutments, and exert their thrust in that direction, are described under BRIDGE. Any other form of arch being more difficult of construction was of rare occurrence until the introduction of railways; the usual plan in carrying a road over a stream, being to construct the bridge at right angles, and to divert the course of the road so as to accommodate it, as shown in Fig. 1994, in which the road, the direction of which is indicated by the dotted line *r r*, is carried over the stream S S in the direction of the curved line, in order that the arch of the bridge may be at right angles to its abutments. In a railway, however, the introduction of these curves would be highly objectionable, [see RAILWAY,] and the necessity for carrying the line in a straight direction over common roads, canals, &c.

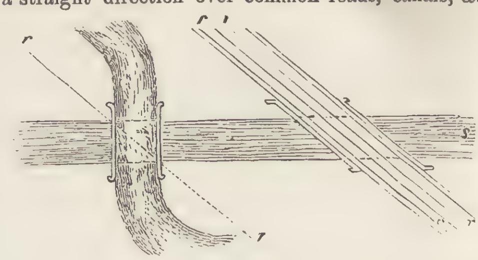


Fig. 1994.

led to the application of the skew-bridge, or oblique arch, in those cases where the line of railway intersected the road or canal, &c., obliquely, as in Fig. 1994, where *s* is the stream, and *r r* the double line of railway. The introduction of the skew-arch on the Liverpool and Manchester Railway, by George Stephenson, was regarded as a complete novelty; but the writer of the article SKEW-BRIDGE, in the *Penny Cyclopædia*, refers to the article OBLIQUE ARCHES, in *Rees's Cyclopædia*, which is said to have been written by an engineer named Chapman, who mentions oblique arches as being in use prior to 1787, when he introduced a great improvement in their construction. Down to that period such arches had been constructed in the same way as common square arches; the voussoirs being laid in courses parallel to the abutments. In such a case, it is evident that only a portion of the arch would be supported by the abutments, the other portions being sustained by the mortar only. In constructing a bridge over the Kildare canal, Mr. Chapman wished to avoid the diverting of certain roads, and he was led to the invention of a method of constructing oblique arches upon a sound principle, the leading feature of which, according to him, was, that the joints of the voussoirs, whether of brick or stone, should be

rectangular with the face of the arch instead of being parallel with the abutments. The courses would thus be laid in the manner indicated by the dotted lines, Fig. 1995. A bridge on this plan near Naas, called the Finlay bridge, crossed the canal at an angle of only 39°, the oblique span being 25 feet, and the height of the arch 5 feet 6 inches. Mr. Chapman remarks that the lines on which the beds of the voussoirs lie are obviously spiral lines, to which circumstance much of the singular appearance of oblique arches may be attributed.

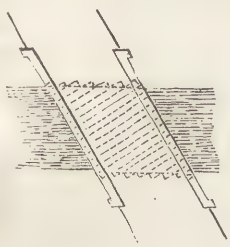


Fig. 1995.

Skew-bridges are now very common, and many others are of considerable obliquity. At Boxmoor, on the North Western Railway, is a brick arch, of which the angle is 32°, the square span 21 feet, and the oblique span 39 feet.

Various methods have been proposed for forming the voussoirs with accuracy, and disposing them with advantage. In the year 1838, Mr. Nicholson read before the British Association, for the advancement of science, a paper on the principles of the oblique arch for the guidance of Engineers. The following is an abstract of this paper. According to Mr. Nicholson, the principles of the oblique arch require, "that 5 of the faces of each stone be prepared in such a manner that 4 of them shall recede from the fifth; and when the stones are arranged in courses, the surfaces of the fifth face shall form one continued cylindric surface, which is the intrados, and the other 4 surfaces shall form the beds and ends of the stones on which they join each other. In every course, two of the opposite surfaces of the first stone, two of the opposite surfaces of the second stone, and so on, shall form two continued surfaces throughout the whole length of each course; and the edge of each of these continued surfaces in the intrados shall be a spiral line. If a straight line be drawn through any joint in one of the spiral lines, perpendicular to the axis of the cylinder, the straight line shall coincide with that continued surface which is a bed of that course, and the straight line thus drawn shall be perpendicular to a plane which is a tangent to the curved surface of the cylinder at that point in the spiral line; therefore the straight line thus drawn shall be perpendicular to another straight line which is a tangent to the spiral at that point. When the intrados is developed, the spiral lines which form the edges of the courses shall be parallel, and their distances shall be equal; and the spiral lines which are the edges of the ends of the stones shall be developed in straight lines, perpendicular to those lines which are the developments of the spirals of the edges of the courses. It is evident that each of these spiral lines will have a certain radius of curvature, and that this radius of curvature, at any point of the spiral line, will be equal to the radius of curvature at any other point in the same spiral; and that the radius of curvature at any two given points in two spiral lines, which have parallel developments, are equal to one another. Therefore, if two points be taken in a spiral line, and if a straight line be drawn from one of them parallel to the axis, and if through the other, the cylinder be cut by a plane perpendicular to the axis, and if the surface of the cylinder be developed, the development will be a right-angled triangle, of which the quotient arising by dividing the product of the square of the hypothenuse and the radius of the cylinder by the square of the development of the circular arc intercepted between the spiral and the straight line, will be the radius of curvature of that spiral. By these principles the geometrical construction of an oblique arch may be easily made for the use of the workmen, or calculations of all the parts may be expeditiously and accurately performed by the engineer; it is only necessary to have given the angle of obliquity of the acute-angled pier, the width of the arch within its abutments, the height of the intrados above the level of the springing, the perpendicular distance between the planes of the two faces, and the number of arch stones in each elevation, in order to construct the arch."

The writer of the article Skew-Bridge, in the *Encyclopædia Britannica*, opposes this theory, and states his opinion that the most perfect method of constructing a skew-arch, is to cut the stones so that two of the opposite sides of each stone, or at least the middle part of these sides, may be as nearly as possible at right angles, both to the soffit, and also to the direction of the passage over the bridge.

Mr. Buck, in his Treatise on Skew Bridges, states that the erection of these structures increases in difficulty with the obliquity of the angle from 90° to 45°, which is supposed to be the most hazardous angle for a semicircular arch; but that, beyond that point, the difficulty does not increase, but rather diminishes to about 25°, which appears to be about the limit for a semi-cylindrical arch. Mr. Buck states, that oblique elliptical arches are deficient in stability, more difficult to execute, and more costly than semicircular or segmental arches.

Curved iron ribs, or girders, are applicable to the oblique as well as to the square arch, since each rib can always be placed in a plane which is both vertical and runs in the direction of the upper passage. The girders are laid parallel, but the end of each girder is in advance of the one preceding it, as in the ground plan, Fig. 1996, the dotted lines showing the situation of the ribs which support the platform. Our railways exhibit some fine examples of these structures.

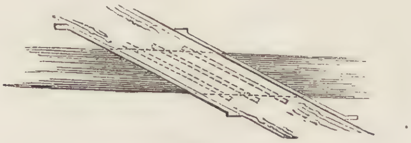


Fig. 1996.

SKIN. See Gelatine—Leather.

SKIVE, a name sometimes applied to the iron lap used by the diamond polishers in finishing the facets of diamonds. It is charged with fragments of diamond powder which are burnished into its surface. The Dutch diamond cutters call it a *schyf.* See CARBON—LAPIDARY WORK.

SLAG. See IRON.

SLATE. Under this word are included a variety of substances, of which the following is a brief account. *Mica-slate*, a mountain-rock of vast extent, composed of quartz and mica. Its structure is foliated, depending on the large proportion of mica. It is thin and slaty, and breaks with a glistening or shining surface. Its usual colour is grey or silvery grey. The more compact varieties are used for door and hearth stones, for flagging, and for lining furnaces. Dana states that the finer arenaceous varieties make good scythe-stones. *Hornblende-slate* resembles mica-slate, but is less glistening, and does not break into such thin slabs. Its toughness makes it a useful flagging. *Talcose-slate* contains talc intead of mica, and hence it has a more greasy feel that mica-slate. It is used for scythe-stones and hones. [See HONE or HONE-SLATES.] *Chlorite-slate* is of a dark-green colour, similar to talcose-slate. *Argillaceous-shale*, or *clay-ate*, has the same constitution as mica-slate; but he particles are so fine as not to be distinguished. Shale is usually distinguished from clay-slate in having a less perfect structure, and being more brittle. The schists include the coarser varieties. [See SCHIST.] Clay-slate is abundant in Great Britain. It is found in the Highlands of Scotland from Lochlomond by Callender, Comrie, and Dunkeld, resting on, and gradually passing into, mica-slate. Roofing-slate occurs in Cornwall and Devon, in various parts of North Wales and Anglesea; in the north-east of Yorkshire, near Ingleton, and in Swaledale; also in Cumberland and Westmoreland. It also occurs in Wicklow, and other mountainous parts of Ireland. The slates exhibited in the Great Exhibition are noticed in the INTRODUCTORY ESSAY, page lxxxi.

The best beds of roofing slate improve in quality as they lie deeper beneath the surface. The blocks are got out by blasting. They are split into sheets, sometimes exceeding 8 feet by 4, by means of long, wide, and thin chisels, applied on the edge, parallel with the laminæ, and struck with a mallet or hammer; cross grooves are then cut on the flat face so as to divide the slabs into the required lengths, which are separated by a blow with the chisel. Each piece is next split into thinner leaves by applying fine chisels to the edges. Each leaf is then roughly dressed on a block of wood with a chopping-knife, as will be explained more particularly in the next article. By long exposure to the air after having been quarried, the blocks may lose their property of being divided into thin laminæ. In such a case the blocks are said to have "lost their waters." Hence, in a slate quarry, the number of splitters ought to be proportioned to the number of block-hewers. The blocks are rendered more fissile by frost, but a subsequent thaw makes them refractory; another frost partly restores the property of splitting. After a succession of frosts and thaws the quarried blocks can no longer be split up into leaves. The desirable properties of roofing slate will be noticed under the next article.

Slate is now used for chimney-pieces, internal decoration, and furniture. For which purpose the large sheets procured by splitting the blocks, are sawn into rectangular pieces and slabs by means of circular saws with rather a slow motion. The process of sawing is rather one of crushing than cutting, and the slate is carried up to the saw by means of machinery, so that it cannot recede from the saw-teeth. The saw requires to be sharpened about 4 times a-day. These slabs are then planed for billiard-tables, &c. in machines which resemble the planing machines used for metals. The planing tools are about 6 inches wide: the jambs for chimney-pieces and other mouldings, not exceeding this width, are planed with figured tools of the full width. Slate is ornamented after the manner of papier maché and china: imitations of marbles and granites being supplied at one-third the prices of marble, for which purpose the slate is rubbed smooth, then japanned to resemble black marble, or of various colours and devices, like tea-trays: the japan is hardened by baking the articles; they are then smoothed with pumice-stone and polished with rotten-stone, as described under JAPANNING. Mr. Henning made use of slate as the material for his moulds or intaglio engravings of the bas-reliefs of the frieze of the Parthenon and other antique marbles. Pumice-stone gives a grain to slate suitable for writing on: the greyness produced by the pumice may be removed by a slight rub of oil, or a wash of common writing-ink allowed to dry on. Slate makes a good drawing-board.

Dana states that slate rocks are used for grave-stones. "We cannot go through New England cemeteries without frequent regret that a material, which is sure to fall to pieces in a few years, should have been selected for such records."

Whet slate or *Turkey hone* is noticed under HONE. *Drawing-slate* or *black-chalk* is used in crayon drawing. The best kinds are from Spain, Italy, and France. It is also found in Caernarvonshire and the island of Islay. Its colour is greyish black: it is very soft, sectile, easily broken, and adheres slightly to the tongue; its density is 2·11. *Adhesive*-slate is of a light greenish-grey colour; it is readily broken; its streak is shining, and it adheres strongly to the tongue; it absorbs water rapidly, with a crackling sound and the emission of air-bubbles. *Bituminous shale* is a slate clay impregnated with bitumen. [See SHALE—ASPHALTUM.] *Slate clay* is one of the alternating beds of the coal measures. [See COAL.] It is an infusible compound of alumina and silica, and is used for making fire-bricks. Stourbridge clay is a variety of this schist. [See IRON, sec. vii.—POTTERY and PORCELAIN, sec. iii.]

SLATING is the art of covering the roofs of buildings with slates. The slates used in and about the metropolis are for the most part from Bangor in Caernarvonshire; they are of a light sky blue colour;

slates from Westmoreland are of a dull greenish hue. Scotch slates are not much esteemed. *Westmoreland slates* are from 3 feet 6 inches to 1 foot in length, and from 2 feet 6 inches to 1 foot in breadth. *Welsh rags* are next in repute, and are nearly of the same dimensions as the Westmoreland slates. *Imperials* are from 2 feet 6 inches to 1 foot in length, and about 2 feet wide. *Duchesses* are about 2 feet long and 1 foot wide. *Countesses* run about 1 foot 8 inches in length by about 10 inches in width. *Ladies* are usually about 15 inches long and about 8 in width. They are sold by the thousand of 1200. There are also *Dennybole slates* and *Tavistock* slates; of the latter those called *doubles* run about 13 inches in length by 6 inches in width.

Slate should be of a fine sound texture, since if absorptive of moisture it will cause the boarding beneath it soon to become rotten. Good slate is very durable, and its value may be estimated by striking it, when, if good, it will yield a clear bell-like sound. The light blue slates are said to retain moisture much less than the deep black-blue variety. Good slate is hard and rough to the touch, while an absorbent variety has a smooth greasy feel. The value of slates may be tested by setting them up edgewise in water which reaches about halfway up the slate: if in the course of 6 or 8 hours they draw water and become wet at the top, they are spongy and absorbent: the smaller the height to which the water rises the better the slates. A more accurate test is to weight pieces of slate at a certain temperature; to allow them to remain in water for 12 hours; then to take them out and wipe them dry. On weighing them again their comparative values will be indicated by the increase of weight, those which have absorbed least water being most valuable.

The slates as supplied from the quarry are squared and sorted by the slater, the largest being selected for the eaves. Each slate is examined, the strongest and squarest end selected, and the slater holding it a little slanting upon and projecting about an inch over the edge of a small block of wood cuts away one of the uneven edges of the slate with an iron knife or chopper, called a *saixe, sax*, or *zax*, about 16 inches long and 2 in width, somewhat bent at one end, with a beech handle at the other; on its back is a projecting piece of iron about 3 inches long drawn to a sharp point. He next with a slip of wood gages the other edge parallel to the first that was trimmed, and having shaped this also, squares the ends, and lastly, with the sharp point on the back of the zax, pecks two small holes through the slate for the passage of the nails used for fastening the slate to the roof. The upper surface of a slate is called its *back*, the under surface its *bed*, the lower edge the *tail*, and the upper edge the *head*. The nail-holes should be made as near to the head as may be without breaking the slate, and at a uniform distance from the tail. Except in the most inferior work every slate should be fastened by 2 nails. The nails used are of copper, zinc, or tinned iron.

The house-carpenter prepares a base or floor for the slates. For *doubles* and *ladies* boarding is required to ensure water tight covering. The boards should be laid even, and be well secured to the rafters with close joints. The larger kinds of slates will lie firmly on *battens* or narrow portions of deal about $2\frac{1}{2}$ to 3 inches wide, and $\frac{3}{4}$ inch thick for countesses, but thicker for heavier slates. The slates should all be of the same width, and the edges true. The battens are nailed to the rafters at the gage to which the slates will work. That portion of each course of slates which is exposed to view is called the *margin* of the course: the width of the margin is the *gage*. The *bond* or *lap* is the distance which the lower edge of one course overlaps the slates of the next course below it, measuring from the nail-hole. The bond should not be less than 2 inches, and need not be more than $3\frac{1}{2}$ inches: the half of what remains is called the *gage*. Thus for a slate 2 feet 3 inches in length, if the bond be 3 inches, the gage will be 1 foot.

The slater first nails down all round the extreme edges of the roof slips of wood about $2\frac{1}{2}$ inches wide, $\frac{3}{4}$ inch thick on one edge, and chamfered to an arris on the other: these are termed *tilting fillets*. He then begins to lay the slates, beginning at the eaves, where he uses the largest slates, setting their lower edges to a line, and securing them by nailing them down to the boarding. See Fig. 1997. In some cases the eaves' course is made double by placing a second row of slates under the first so as to cross and cover all its joints; such slates are pushed up tightly under those which are above them, and are seldom nailed, their own weight and the weight of those above them retaining them firm.

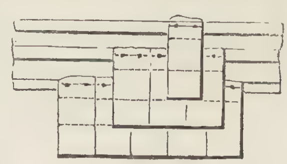


Fig. 1997.

When the eaves are finished the slater strains a line on the face of its upper slates parallel to its outer edge, and as far from it as he thinks sufficient for the lap of those slates which are to form the next course, which is laid and nailed even with the line, and crossing the joints of the upper slates of the eaves, as shown in the figure. This lining and laying of the slates is continued until the slater gets close up to the ridge of the roof, which is covered by an overlap of sheet lead. In nailing a slate it must not be strained or bent, or it will split on some sudden change in temperature. Slating should be pointed or *torched* on the inside with lime and hair in order to exclude the wind and to prevent snow from driving in.

Patent slating, as it is called, is formed by laying wide slates side by side and covering their joints with narrow slips bedded in putty, the overlap at the ends not being greater than the bond in the usual method. Neither boards nor fillets are used, but the slate is screwed to the rafter, its width being sufficient to extend from rafter to rafter; and the covering slips are also screwed as well as bedded in putty. Slating of this kind may be laid at so small an elevation as 10°: in ordinary slating the angle should not be less than 25°. The objections to patent slating are that it is

liable to become deranged by a very slight settlement of the building, and the putty is apt to become dislodged and let in the rain.

Slaters' work is measured by the square of 100 superficial feet, with an allowance for cutting the slates at the hips, eaves, round chimneys, &c. Slabs for cisterns, baths, shelves, &c., are charged by the square foot, according to the thickness of the slab and the work bestowed. Rubbed edges, grooves, &c., are charged per lineal foot.

SLIDE-REST. See INTRODUCTORY ESSAY, p. clx.

SLIP. See SHIP.

SLITTING MILL. See LAPIDARY WORK, Fig. 1273.

SLOTTING ENGINE. See SHAPING-MACHINE.

SLUICE. See DRAINAGE—SEWER.

SMALT. See COBALT.

SMELTING. See IRON—METAL.

SMOKE. See CHIMNEY—WARMING and VENTILATION.

SMOKE JACK. See WARMING and VENTILATION.

SNUFF. See TOBACCO.

SOAP is a compound of certain fatty substances with soda or potash. Its detergent properties depend entirely upon its alkalies, a portion of which combines with the greasy matters intended to be removed by washing, rendering them soluble or miscible with water without corroding. The caustic alkali alone would act more powerfully as a detergent, but it would corrode organic substances if used freely, and destroy some of the colours of dyed goods. In ancient times the alkali was so used, in a more or less caustic state, and is still employed by cottagers in the lye obtained by filtering water through wood ashes. The Hebrew word *borith*, which, in Jer. ii. 22, has been rendered *sope*, refers to vegetable lye, or potashes. In another passage (Mal. iii. 2) the *fuller's sope* is from the Hebrew word *nether*, which is mineral lye or soda. The first mention of soap, properly so called, is said to be by Pliny, who declares it to be an invention of the Gauls, although he prefers the German to the Gallic soap: he states that soap was made of tallow and wood ashes; that the best was made of goats' tallow and beech-wood ashes, and that there were two kinds of soap, *hard* and *soft*.[1] Soap is also mentioned by Geber, in the second century, and at a later period is frequently referred to by the Arab writers as being used not only for detergent purposes, but also as an external remedial application. It would be difficult to trace the history of soap to modern times: there is, however, evidence of the manufacture having been conducted in the reign of Queen Anne almost precisely as at present, a clear proof of the injurious influence of the excise on the manufacture. In France, and other countries, the art of making toilet soaps, as well as common varieties, has been constantly improving, and the export trade of France is large. We are, however, thankful that the soap-tax in Great Britain is at length repealed, and we may hope to see the manufacture speedily recover from its stationary condition, and occupying a higher position among the chemical arts, enrich science with new facts, and open up new branches of industry. Indeed there is scarcely any subject that is more likely to reward invention than a well-directed inquiry into the various combinations of the fats and oils with alkalies. The innumerable metamorphoses which the fats and oils are capable of undergoing; the small number of elements concerned in their composition; the large number of cheap substances in which those elements exist (as in coal, wood, bituminous shale, &c.), lead to the hope that the chemist may one day be able to obtain from them marketable substances resembling tallow, wax, and spermaceti.

The manufacture of soap has been greatly assisted and promoted by Chevreul's researches on the nature of fats, [see CANDLE—OILS and FATS], which have satisfactorily explained the nature of saponification; and by Leblanc's method of procuring soda from common salt, [see SODIUM,] which gradually liberated the manufacture from its dependence on barilla and kelp as sources of the alkali. It is stated in the Jury Report, Class xxix., that Mr. James Muspratt, who was the first to carry out Leblanc's process on a large scale in England, "was compelled to give away soda by tons to the soap-boilers before he succeeded in convincing them of the extraordinary advantages to be derived from the adoption of this material. As soon, however, as he had effected this, and when the soap-boilers discovered how much time and money they saved by using artificial soda, orders came in so rapidly that Mr. Muspratt, to satisfy the demand, had his soda discharged red-hot into iron carts, and thus conveyed to the soap-manufactories. From that period a constant race was kept up between soap-making and the artificial production of soda; every improvement in Leblanc's process was followed by an extension of the soap-trade, and it is a curious fact, that the single sea-port of Liverpool exports annually more soap at present than did all the ports of Great Britain previous to the conversion of chloride of sodium into carbonate of soda. The manufacture of soap has, on the other hand, been a powerful stimulus to the preparation of soda, and of the important secondary product, hypochlorite of lime (bleaching powder), which are so intimately allied with almost all branches of chemical trades; thus soap occupies one of the most important pages in the history of applied chemistry. The increase in the consumption of this article has led, moreover, to the discovery of new materials for its production; it has opened new channels to commerce, and thus it has become the *means* as well as the *mark* of civilization. Almost simultaneously with the employment of soda, the oils of the cocoa-nut and the palm have been introduced into the manufacture of soap." The increasing consumption of these oils will be seen from the following statement of imports into the United Kingdom:—

	Palm-oil.	Cocoa-nut oil.
1820	17,456 cwts.	8,353 cwts.
1830	213,476 —	8,534 —
1840	315,503 —	42,428 —
1850	447,796 —	98,039 —

(1) An historical notice of soap will be found in Beckmann's *History of Inventions*.

Tallow is also largely employed in this country in the manufacture of soap, and in France olive-oil is the chief material.[1] Lard, linseed-oil, rapeseed-oil, fish-oil, kitchen-stuff, bone, fat, and common rosin, are also in great demand by the soap-maker.

Referring to the articles CANDLE and OILS AND FATS for the chemical constitution of fats, it is only necessary to state in this place enough on the subject to render the details of soap-making intelligible. Fats consist of two proximate fatty substances—*oleine*, which is fluid at common temperatures, and *stearine*, which is solid. A fat is solid, soft, or fluid, at ordinary temperatures, according to the proportions of these two bodies. Stearine may also contain an analogous body, *margarine*, in various proportions: the solid fat or tallow of the sheep contains chiefly stearine; lard and olive oil contain chiefly margarine; while the solid fat of palm-oil is denominated *palmitine*, and that of cocoa-nut oil *cocine*. Stearine, margarine, oleine, palmitine, and cocine, are in their turns compounds of certain fatty acids with *oxide of glyceryl* or *glycerine*. Thus the acid of oleine is *oleic acid*, which, in combination with the oxide of glyceryl of the oleine forms *oleate of glycerine*. Stearine contains *stearic acid*, which forms with the oxide of glyceryl of the stearine, *stearate of glycerine*. So also margaric acid forms *margarate of glycerine*, and so on. Now these fatty compounds, stearine, oleine, &c., are decomposed by the free alkalies, potash, or soda, their acids quitting the glycerine to unite with the alkalies, thus forming a soluble soap, the glycerine remaining behind in the mother liquor. The hard soaps of commerce, when made with oils (palm and cocoa-nut oils excepted), are chiefly mixtures of oleate and margarate of soda, with little if any stearate. When the hard soaps are made with animal fats they are mixtures of oleate, stearate, and margarate of soda. Stearine, oleine, &c., are also decomposed by the earths, lime, and magnesia, and by metallic oxides, such as those of lead and zinc. *Lead soap* is an insoluble oleate of oxide of lead: it forms the *diachylon plaster* of pharmacy. *Zinc soap* is an ointment. *Lime soap* is insoluble; it is formed in the shape of a crudy precipitate when soluble soap is mixed with hard water; the carbonate or sulphate of lime in the water and the soap mutually decompose each other; the fatty acids of the soap combine with the lime in the water, and the carbonic or sulphuric acid of the lime unites with the alkali of the soap. No lather can be formed until the whole of the lime is thus taken up.

As in the time of Pliny, soaps are still divided into *hard* and *soft*. The hard are made from fats and vegetable oils, with soda as a base; the soft, from fish oil or vegetable drying oil, with potash as a base. A hard soap may be made with potash if a solid fat be employed; but soda soaps are always harder than potash soaps with the same fatty substance. The stearate of soda, which may be taken as the type of hard soaps, scarcely changes with ten times its weight of water; but the stearate of potash forms therewith a thick paste or viscid solution.

In this country and in the north of Europe white soap is made from tallow and soda. In France, Italy, and other places where the olive-tree grows, an inferior olive oil is used for the purpose. One ton of soap requires from 10 to 14 cwt. of tallow or olive oil; the proportion of alkali varies in different works; but supposing it to be pure and dry, the proportion required for the saponification of different oils and fats varies from about 10 or 14 soda, and from 15 to 20 potash, for every 100 parts oil or fat. In the best Windsor soap the tallow is mixed with about 10 per cent. of inferior olive oil, and in white soap a portion of lard is sometimes substituted for an equal portion of tallow; this prevents the soap from being too hard.

When a soluble soap is made by boiling a solution of soda or potash with stearine, the stearate of soda, or soap, remains suspended in the water of the solution, together with the glycerine, from which it is separated by means of a solution of common salt, in which soap is not soluble, while the excess of alkali, the water, and the glycerine combining with the salt water, the soap separates, floats on the surface, and can be thus removed. Soaps being also insoluble in strong alkaline lyes, the separation is sometimes effected by boiling down the soap to a certain consistence, when it separates from the excess of lye. The soap made with cocoa-nut oil is, however, soluble in very strong brine, so that it cannot be separated by this means unless the oil be largely mixed with other fats. This property of dissolving in salt water renders cocoa-nut oil well adapted to the formation of a *marine soap*. Cocoa-nut oil soap solidifies with a much larger quantity of water than most other soaps. A maker has been known to vend a cocoa-nut oil soap containing 75 per cent. of water, 25 to 35 per cent. being a large quantity for any but potash soaps, and these seldom contain more than 50 per cent. The French makers allow 30 per cent of water for mottled soaps, and 45 to 46 per cent. for white soaps; but cases have been known in which soaps combined with from 83 to 154 per cent. of water have been sold. *Floating soaps* contain a large proportion of water.

Most of the potash or soda soaps are readily soluble in alcohol: on evaporating the solution, the soap remains in a transparent state, forming *transparent soap*.

When an insoluble soap is formed, as by boiling oleine with oxide of lead in making diachylon, the oleic acid of the oleine combines with the metallic base forming the insoluble soap, while the glycerine of the oleine separates in combination with the water.

Common rosin, consisting chiefly of pinic acid, with a little sylvic and colophonic acids, unites with alkalies under certain conditions. Thus when rosin is

(1) Now that the duty is taken off soap, the manufacturer may find it to his interest to adopt some of the French processes. They are well described in one of the Manuels-Roret, entitled, "Nouveau Manuel Théorique et Pratique du Savonnier, ou l'Art de faire toutes sortes de Savons; par Madame Gacon-Dufour, et MM. Julia de Fontenelle, Thillaye et Malepeyre." Paris, 1852.

boiled with soda, it forms chiefly *pinate of soda,* which gives the distinctive character to *yellow soap.*

The alkali used in making soap should be caustic. Although the carbonates of the alkalies by long boiling will saponify the fats, the operation is tedious, and the saponification incomplete. The crude alkali sent to the soap-works is usually a carbonate; it is mixed with recently slaked lime and a certain bulk of sand, for facilitating the process of filtration. The mixture is placed layer by layer in a large tank, the layers being separated by rush matting. The tank

Fig. 1998. ALKALI TANKS.

is filled up with water, and allowed to stand for from 12 to 18 hours: a plug is then removed from near the bottom of the tank, the lye is drawn off, and the tank again filled up with water. This operation is repeated 5 or 6 times; the leys are kept in separate reservoirs, and are called, *first running, second running,* &c. In this operation the lime takes carbonic acid from the alkali, leaving the latter in a caustic state.

Soap is usually manufactured by one of two processes. The first is the *cold process,* in which the materials are combined at a temperature below the boiling point of water. This process is also called the *small boiler process,* on account of the comparatively small size of the vessels in which it is conducted. The alkali used in this process is prepared from the purest commercial soda, and is concentrated by evaporation. The chloride of sodium and sulphate of soda, with which the soda is contaminated, not being soluble in a strong solution of soda, they crystallize out when the lye is left for some days. The proper proportion of fat is melted, and the lye of known density is measured out, heated and stirred into the melted fat. Saponification now takes place, and the soap solidifies on cooling. By this process the glycerine is contained in the soap, and either the fat or the alkali is in excess on account of the difficulty of exactly proportioning the two.

The other method, which is the common one, is termed the *large boiler process,* the boilers, or *coppers* as they are called, being of large size, each capable of holding many tons. It is made of cast-iron in 3 distinct pieces, which are united by a cement composed of iron rust, sal ammoniac, and sulphur; the top and middle pieces called *curbs* are set in masonry, and heat is applied either by means of steam or by a small open fire, acting on the lower part of the copper. All the oil or tallow is introduced at one batch into the copper, but the alkali is added in several distinct portions. The weakest solution of caustic lye is pumped up into the copper, (see Fig. 1998.) Heat is applied until the lye ceases to be caustic. Salt may be added with the lye or in the present stage. It is better to add a certain portion with the lye, since the lye and the tallow form a uniform emulsion, which is liable to burn to the bottom of the boiler, were it not for the solution of salt, which forms a protective layer beneath the saponifying mixture. On allowing the contents of the copper to cool, the spent lye and the salt settle at the bottom of the copper, whence they are pumped up, the excise regulations not allowing them to be drawn off from below. This spent lye, containing glycerine, sulphate of soda, and chloride of sodium, is thrown away to waste. This first boiling forms what is called an *operation,* and 3 or 4 operations with leys of gradually increasing strength are required to *kill the grease,* or to cause saponification. It is known when the tallow is saponified, when a little of the compound is squeezed between the finger and thumb, and allowed to cool. If the process is complete, it will separate from the finger as a hard cake; it will have lost the peculiar taste of grease, and have acquired a slightly alkaline taste. If, on the contrary, any tallow remain unsaponified, it oozes out by pressure, and is evident both to the sight and taste. The more certain test of the saponification being complete is, to decompose a portion of the soap

Fig. 1999. BOILING.

by means of an acid, and if the resulting grease is not entirely soluble in boiling spirits of wine, the saponification is imperfect. In making common yellow soap the resin is usually added at this stage, the

quantity being ⅓d or ¼th the weight of tallow employed.

But even when the saponification is complete the soap is not in a fit state for the market. It consists of innumerable globules, all separate and distinct from each other: these must be made to coalesce into a homogeneous mass, for which purpose the soap is *fitted; i. e.* the contents of the copper are fused in a weak ley or in water, and the boiling kept up for some time, the mass being prevented from boiling out of the copper by dashing shovels into it so as to break the froth and favour the evaporation. During this process, in making *white* or *curd soap*, the black impurities of the materials (called *nigre*) fall to the bottom; but in making *mottled soap*, the mixture is left in a thick or viscid state, so that the nigre cannot subside. When the process is finished, the fire is extinguished, and the lid is shut down. After the lapse of one, two, or three days, according to the kind of

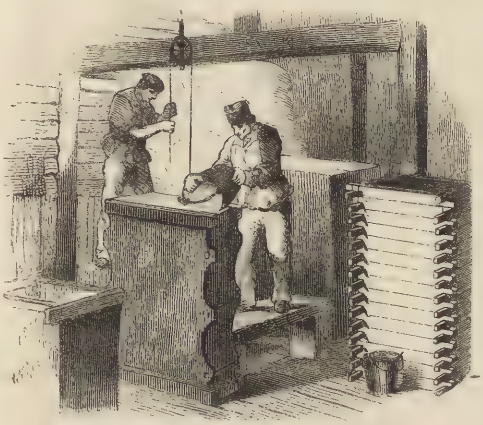


Fig. 2000.—FILLING THE FRAMES.

soap, the semi-fluid mass is ladled out from the precipitated ley into rectangular *frames*, or *sesses*, as they are called in Liverpool, of certain dimensions prescribed by the Excise, viz. 45 inches long by 15 inches wide, interior dimensions: they are each about 10 inches deep, and are made smooth, so as to fit closely together: they are piled up one upon another, and bound tightly together by means of iron screw-rods, to the height of from 5 to 12 feet, forming a sort of rectangular well, capable of holding about 2 tons of soap. Within this well the soap cools and solidifies. For yellow soap the frames are of cast-iron. Both kinds of frames are shown in Fig. 2000.

When the soap is solid and cold, the screw-rods are removed, the frames lifted off, and the soap stands as a compact mass, moulded to the interior form of the frames. It is cut by wires into slabs 2 or 3 inches thick, and these are subdivided into bars for sale. These bars are piled away crosswise, in the form of a well, interstices being left for the circulation of air. The soap is allowed to remain in this condition for some time, that the solution of salt, with which the soap is slightly impregnated, may exude.

The nigre which is left in mottled soap consists chiefly of sulphuret of iron, produced by the action of the lye (which always contains a small quantity of sulphuret of sodium) on the boiler. At Marseilles

Fig. 2001.—CUTTING THE SOAP INTO BARS.

and other places where olive oil is used in making soap, a quantity of green copperas (sulphate of iron) is added, in which case the mottling is produced both by the black sulphuret of iron and by the oxide of iron, the red portion, which forms a true *iron soap*. When the soap is ladled out of the boiler it is of a uniform slate tint, but as it cools the metallic portions separate into nodules, and by the trickling of the excess of lye through the mass, they assume those forms to which the term *mottled* is applied. Mottled or *marbled* soap is also formed by sprinkling a small quantity of lye, strongly impregnated with sulphuret of iron, upon the soap immediately after the last boiling: this, filtering slowly through the soap, produces the required effect.

It will be seen, from the foregoing details, that the large-boiler-process is a skilful adaptation of chemical processes, whereby a very pure chemical compound is obtained from comparatively impure materials.

Patents have been taken out from time to time for varying the processes, but they do not appear to have met with much success in this country, probably on account of the inflexible requirements of the Excise laws preventing hitherto the experimental inquiry into new suggestions. Mr. A. Dunn proposed to effect the saponification in close vessels at the high temperature of 310° Fahr. Mr. Hawes, on the contrary, proposed to make use of strong lyes, and to mix by mechanical action in a comparatively cold state. The product is then boiled and fitted as usual. Both these plans have been patented. Other patents for supposed improvements, are in reality (as it is remarked in the excellent Jury Report on Soap) plans for the adulteration of soap; such, for example, as the preparation of soap from bones, fish, &c. which is merely introducing an adulteration of gelatine. A similar censure applies to plans for the introduction of Cornish clay, fuller's earth, &c. into soap. The *silicated soap*, properly so called, is an excellent article. It is a mixture of silicate of soda with hard soap to the

extent of one-fifth. In this case the additional quantity of alkali increases the detergent properties of the article. It is, however, usually made by mixing with the pasty soap while in the frames a quantity of Cornish clay previously rubbed up with caustic lye. It is stated that such soaps can be used at sea with salt water: hence they probably contain cocoa-nut oil.

Floating soap is prepared by melting ordinary soap with the addition of a certain proportion of water, and then beating it into a thick froth by means of a paddle until it occupies thrice its original bulk.

Curd or white soap contains in 100 parts, grease 61, soda 6·2, and water 32·8. Curd soap is too hard and compact for domestic use, but the introduction of lard for white, and rosin for yellow soap, has the effect of softening it. Rape-oil, in the proportion of one-fifth, has a similar effect on olive-oil soap. As rosin contains no glycerine, it is not capable by itself of forming soap with an alkali. In making yellow soap, palm-oil is now generally substituted for tallow; about 3½ parts of palm-oil being used for every one part of rosin. If the rosin be in larger proportion (as it often is), the soap is soft and dark-coloured. The rosin is introduced in coarse powder, with the last charge of lye, when the saponification of the palm-oil is nearly complete. It is well mixed by agitation, and the boiling continued for some hours, lye being occasionally added, to preserve an excess of alkali until the soap is fully formed, when the lye is withdrawn, and weak fresh lyes added, for eliminating the glycerine. The resinous scum which rises to the surface is removed for another operation, and the soap is conveyed to iron frames to solidify. Yellow soap usually contains 1 part soda, from 10 to 11 parts oil and rosin, and from 24 to 50 per cent. of water; the latter quantity, however, is far too much. Of late years the soap-maker has been supplied with fine American rosin, which is much purer and of a paler colour than the English; hence yellow soap is much improved, and is now called *primrose soap* from its pale yellow colour. Yellow soap is produced in the largest quantities in England. Mottled soap is next in importance. Curd soap is used largely by the cloth manufacturers of Yorkshire, and the lace and stocking bleachers of Nottingham. Soap made from kitchen stuff, bone fat, &c. is too soft for general use; but the introduction of about $\frac{1}{20}$th of fused sulphate of soda, is said to harden it, improve its colour, and give a peculiar unctuous feeling to the water.

Soft soap. Soda or hard soaps differ from potash or soft soaps, chiefly by the manner in which they combine with water. In the one, the water is chemically combined; in the other, it is merely in a state of mechanical mixture. In this country, soft soap is usually made with whale, seal, olive, and linseed oils, and a certain quantity of tallow, the object of which is to produce white granulations of stearate of potash, called *figging*, from the resemblance to the granular texture of a fig. These granulations are improperly regarded as proofs of the good quality of the soap, and are on this account sometimes imitated by the addition of starch, or slaked lime.

The lyes used should be caustic, and of different strengths. A portion of the oil being poured into the pan, is heated to the temperature of boiling water, when the weaker lye is introduced. The mixture is then gently boiled, and stronger lye occasionally added, until the saponification is thought to be complete; this is judged of by the boiling becoming less tumultuous, the froth subsiding, and the paste becoming transparent and thick. The process is thought to be complete when the paste ceases to have an acid taste, and when a portion, put out on a cool glass plate, assumes the proper consistency. It is then packed in casks for the market. The granulations above spoken of do not usually appear till two or three weeks after the soap has been made, and in warm weather not at all. The general composition of soft soap is—in every 11 or 12 parts, alkali 1 part, fatty acids from 4½ to 5 parts, water and impurities from 5 to 6 parts. The deliquescent nature of this soap renders it impossible to separate it from the lyes, as in the case of hard soaps; hence the glycerine and saline impurities of the lyes remain in the soap.

Some oils, such as hempseed oil, impart to the soap a greenish colour which is much esteemed. Manufacturers are always skilful in preserving appearances which form the popular test of the goodness of an article, and hence this greenish hue is imparted to soft soap by the addition of a little indigo.

Soft soap is largely used for cleansing woollen yarns and for stuffs, and also in linen bleach-works. Its applications in the laundry are very limited.

Toilet soaps are usually prepared by remelting and clarifying, curd or white soap, and adding various perfumes, colours, &c. The restrictions of the Excise have hitherto rendered it very inconvenient to make toilet soaps directly from the requisite ingredients as of course is done on the continent. In Ireland, where there is no soap duty, the perfumer generally makes his own soap by the cold process. The *marbling* of fancy soaps is produced by rubbing up the colouring material, such as vermilion or ultramarine, with a little olive oil or soap, and taking a small portion on a pallette knife, it is pushed through the melted mass, and moved about according to the taste of the operator. *Coloured soaps* are produced by mixing mineral colours with the melted mass: the pink colour of *rose-soap* is produced by vermilion: *blue*, by means of artificial ultramarine; and *brown*, by means of various ochres. *Transparent soap* is made from white tallow soap, cut into shreds, dried, and heated in a still, with an equal weight of spirits of wine, with turmeric, or archil. When the spirit is saturated, the heat is withdrawn, and the solution left to settle. It is then poured into tin frames to solidify, and after exposure to dry air for a few weeks, is cut up into cakes for sale.

The cakes, or tablets, are formed by placing a soft mass of soap in a mould fixed in a lever-press: the mould consists of a top and bottom die fitting into a loose ring: by a sudden pressure the shapeless mass assumes the form of the ring, and is embossed on the top and bottom. Soap is ornamented with coloured

cameos by first forming the cake at a press, which makes depressions for the reception of the differently coloured soap, which is put in by hand, and the coloured portion is embossed at a second press.

Windsor soap was formerly manufactured with mutton fat or suet. On the continent the makers mix with the fat, olive oil or tallow in the proportion of 20 to 35 per cent. The saponification being complete, the perfumes are added in the proportion of 9 parts per 1,000. They consist of oil of caraway, 6 parts; oil of lavender, 1½ part; oil of rosemary, 1½ part. Or, to every 1,000 parts of soap, add 6 parts oil of caraway and 2 of bergamot.

Notwithstanding the obstruction occasioned by the excise laws, the manufacture of soap is more extensive in the United Kingdom than in any other country of the world. In 1850 there were 329 soap-makers,[1] and 68 remelters or perfumers. Ireland, not being subject to duty, the quantity there made cannot be ascertained, but in Great Britain the quantity made in the above year amounted to 204,410,826 lbs., and yielded a duty of 1,299,232*l.* 10*s.* 2*d.* Of this quantity, 12,555,493 lbs. were exported to foreign parts, the drawback on it being 82,308*l.* 18*s.* 9*d.* The total quantity consumed in Great Britain, therefore, amounted to 191,855,333 lbs. Of this quantity, 22,858,382 lbs. were used by manufacturers of woollens, silk, and cotton, on which the duty, amounting to 97,342*l.* 0*s.* 11*d.* was remitted. This leaves the net revenue derived from the soap-duty at 1,119,581*l.* 10*s.* 6*d.* After deducting the quantity exported, and that used by manufacturers, it appears, that 168,996,951 lbs. were consumed for domestic use in Great Britain in 1850, equal to 8 lbs. 1 oz. each person. In the year ending 5th Jan. 1852, there were manufactured in Great Britain 195,077,499 lbs. of soap. Of this quantity England produced 182,714,166 lbs., and Scotland 12,363,333 lbs. In England the quantity is made up of *hard soap*, 169,519,201 lbs.; *silicated soap*, 1,320,033 lbs.; and *soft soap*, 11,874,932 lbs. In Scotland, *hard soap*, 15,206,064 lbs.; *silicated soap*, 7,150 lbs.; *soft soap*, 7,150,119 lbs. The quantity imported into Great Britain in the above year was, from foreign countries, 1,533 cwts. 3 qrs. of hard soap, 158 cwts. 1 qr. of soft soap, and 57 cwts. 3 qrs. of Naples soap: from Ireland, 120,109 lbs. of hard soap, and 1,714 lbs. of soft soap. The total amount of import duty was 1,807*l.*

The excise duty was first imposed in Great Britain in 1711, the rate being 1*d.* per lb. In 1713 it was raised to 1½*d.* per lb.; and in 1782, the duty on hard soap was raised to 2¼*d.*, and on soft soap 1¾*d.* per lb. In 1816, the duty on hard soap was raised to 3*d.* per lb., which continued until 1833, when it was reduced to 1½*d.* per lb. on hard, and 1*d.* per lb. on soft soap. An addition of 5 per cent. was afterwards made to these rates. At the time we are writing, July 1853, a bill is being passed through parliament for the total repeal of the soap-duty.

(1) The number of licensed makers has progressively decreased since 1801, when it was 624. In 1811 it was 522; in 1845, 356. The reason for this decrease is probably the gradually extending operations of some of the large manufacturers.

The effect of the excise regulations has been to prevent improvements in the manufacture, and to exclude it from most foreign markets, by limiting the manufacturer as to the size of the bars, the specific gravity, the choice of materials, and the mode of manufacture. But notwithstanding these obstructions it is gratifying to learn from the Jury Report, that, on comparing the productions of other nations with those of the seven soap-makers who represented the British manufacture, "it is evident that, as regards tallow, palm-oil, and rosin soaps, the British soaps are generally better manufactured. The English toilet soaps are in no respect inferior to those of other countries, and are generally so far superior in their detergent qualities, on account of their being made from soap manufactured exclusively by the large-boiler-process. The high reputation of the so called *Windsor-soap* in all civilized states, is an ample testimony of the estimation in which English toilet-soap is held by the makers of other countries, who adopt its name for any sort they wish particularly to recommend."

SOAPSTONE. See Steatite.

SODA. See Sodium.

SODA-WATER. See Waters Mineral.

SODIUM (Na 24) or Natrium, the metallic basis of soda, was discovered by Sir H. Davy shortly after the discovery of potassium, and by similar means. [See Potassium.] It may be prepared by decomposing carbonate of soda by means of charcoal at a high temperature. The process is similar to that described for obtaining potassium from potash; but as sodium does not combine with carbonic oxide the process is more productive. Thus 1 lb. of carbonate of soda, obtained by calcining the acetate, mixed with ¼ lb. of finely powdered and ¼ lb. of coarsely powdered charcoal, and heated in a malleable iron bottle, yields nearly 5 ounces of sodium, a result still capable of improvement, the whole of the sodium present being about 7 oz. Dr. Gregory remarks, that "from the extreme cheapness of carbonate of soda and the productiveness of the operation, sodium can be prepared far cheaper than potassium, and may in most cases be substituted for that metal, as its affinities are almost equally powerful. Should this metal ever be required on the large scale, it might be obtained for a price little, if at all, higher than that of zinc."

Sodium is a metal of a silver-white colour, of the sp. gr. ·972: it is soft at common temperatures: it fuses at 194°, and oxidizes very rapidly in the air. Placed on the surface of cold water it decomposes a portion of that liquid with violence, but does not take fire on account of its rapid motion and consequent cooling. It takes fire in a solution of gum or starch, which prevents its rapid motion. It also burns on hot water with a bright yellow flame: it also ignites on a moist badly conducting surface. A solution of soda is formed by the combustion in water.

There are two well-defined compounds of sodium and oxygen, the *protoxide* or *anhydrous soda*, NaO, and the peroxide, NaO_2, or, according to some authorities, NaO_3. They resemble the corresponding com-

pounds of potassium. The protoxide is the salifiable base.

The *hydrate of soda*, NaO, HO, is prepared by decomposing a rather dilute solution of carbonate of soda by means of hydrate of lime. The process is similar to that described for forming hydrate of potash, and like that salt may be obtained in crystals from its concentrated aqueous solution. The solid hydrate of soda is a white, brittle, fusible substance, of the sp. gr. 2·0: it is deliquescent, but, in time, dries up again in consequence of the absorption of carbonic acid. The solution is highly alkaline or caustic, and a powerful solvent for animal matter: it is used in vast quantities for making soap. [See SOAP.] The strength of a solution of caustic soda may be determined by approximation from a knowledge of its density by the aid of the following table, prepared by Dr. Dalton:—

Sp. Gr.	Soda per cent.	Boiling point.
1·85	63·6	600°
1·72	53 8	400
1·63	46·6	300
1·56	41·2	280
1·50	36·8	265
1·47	34·0	255
1·44	31·0	248
1·40	29·0	242
1·36	26·0	235
1·32	23·0	228
1·29	19·0	224
1·23	16·0	220
1·18	13·0	217
1·12	9·0	214
1·06	4·7	213

A more perfect method of ascertaining the quantity of real alkali in the hydrates and carbonates of the alkalies is given under ALKALIMETRY.

Carbonate of soda, NaO, CO_2 + 10 HO. This salt, so important to our manufacturers [See GLASS—SOAP, &c.], which is now prepared in vast quantities from common salt, was formerly obtained by the combustion of certain sea-shore and sea plants, the ashes of which afforded, by lixiviation, an impure kind of soda. Two kinds of rough soda were known in commerce, viz. *barilla* and *kelp*, the former being the semifused ash of the *salsola soda*, which was cultivated on the Mediterranean shore of Spain, near Alicant. Impure carbonates named *Varec* and *Blanquette* were made, the former in Brittany, and the latter at Aigue-mortes and Frontignan. At Narbonne it was called *salicor*. Kelp consists of the ashes of sea-weeds, collected upon many of the rocky coasts of Britain, and burnt in kilns or in excavations made in the ground. About 24 tons of sea-weed are required to produce 1 ton of kelp. Kelp is now only of importance as a source of iodine. [See IODINE.] During the war, however, when the duties on barilla and common salt were exceedingly high, the manufacture of kelp was a flourishing one in Scotland. The annual rental of the kelp shores of the island of North Uist alone amounted to 7,000*l*. Scotland at one time furnished annually 25,000 tons of kelp, which has been known to sell for 20*l*. a ton: the usual price was about half that sum. *Native* carbonate of soda is also produced in Egypt, in the desert of Thaiat in the western Delta, where there is a pit 4 leagues long and a ¼ of a league wide, which, during winter, is filled to the height of 6 feet with violet coloured water. On the evaporation of this water, carbonate of soda remains, and is loosened with iron poles. The residue is contaminated with 36 per cent. of common salt, and 16 per cent. of sulphate of soda, besides sand; but after being purified it contains only 10 per cent. of sand, 4 of common salt, and 1 of sulphate of soda. At Shegedin, in Little Cumaria in Hungary, carbonate of soda effloresces on the ground. It is gathered before sunrise: the grey powder is dissolved out by water, the solution evaporated to dryness, and the residue heated to redness for the purpose of destroying organic matter. It contains sulphate of soda and common salt. Carbonate of soda also effloresces abundantly on walls. That found on walls in the towns of Flanders consists of carbonate and sulphate of soda, and is derived partly from the soda-salts in the limestone used in the preparation of the mortar, and partly from soda contained in the coal with which this limestone is burned.

Previous to the revolution of 1789 the soda used in France was obtained from marine plants, as above described, chiefly from the coast of Spain. The wars in which France was engaged with nearly all Europe put a stop to this and other branches of native industry. The importation of potash was also stopped, and all the supplies of that substance that could be obtained in France were devoted to the manufacture of gunpowder. The manufacturers of glass, soap, &c., were thus deprived of an article essential to their very existence. In this emergency the Committee of Public Safety called upon all citizens to place in the hands of Commissioners, without any regard to private interests, any plans for the preparation of soda that might be known. This was accordingly done, and the Commissioners reported, that among the numerous plans submitted to them, that by Leblanc was most practicable, and best adapted to the wholesale dealings of the manufacturer. This plan was adopted, and the first establishment for carrying it out was erected at St. Denis in 1804. After the repeal of the salt duty, the process was introduced into this country, and altogether it has been in use for nearly half a century with little or no alteration in its most important details.

The first part of the process consists in converting common salt, NaCl, into sulphate of soda. This is done in reverberatory or *decomposing furnaces*, as they are called, two of which are shown in Figs. 2002, 2003, the first being the more common, and the second the more improved form. A number of these furnaces are arranged side by side, all discharging their flues into a tall chimney, which is the most conspicuous object on approaching the alkali works from a distance. The floor, or sole of each furnace is of brick, but is sometimes lined with lead, and is usually divided into two compartments, in one of which the liquid portion of the mixture is evaporated, and in the other the residuary sulphate is calcined. In some furnaces the evaporation and calcination are

carried on in the same division. In fig. 2002, in the division B, farthest from the fire, called the *decomposing bed*, the salt and sulphuric acid are brought together.

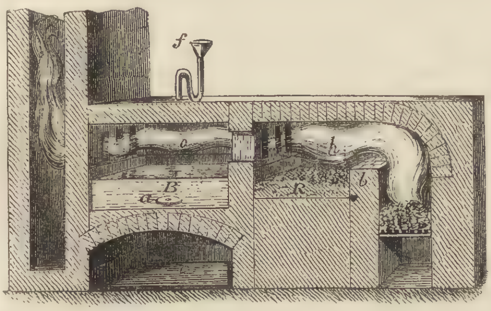


Fig. 2002

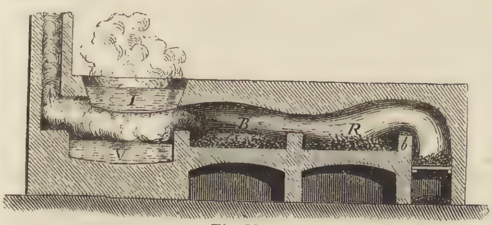


Fig. 2003.

The quantity of salt introduced at one charge varies, according to the size of the furnace, from two or three cwt. to half a ton. A nearly equivalent weight of sulphuric acid is poured very slowly on the salt through an opening in the roof, closed at other times with a leaden plug, or through a leaden syphon funnel *f*, as in the figure. The quantity of acid is so adjusted that the salt may be in excess, which is far more desirable than an excess of acid. The mixture is equalized by stirring with an iron rake covered with sheet lead. Abundant fumes of hydrochloric acid result from the decomposition, which are conveyed through the flue into the chimney, and discharged into the air, or they are condensed into liquid hydrochloric acid; but as the consumption of this acid bears only a small proportion to that of soda, it is generally more profitable for the manufacturer to allow the acid fumes to escape into the air, where, on emerging from the top of the chimney, they form a white cloud of acid, which rains sterility and desolation on the surrounding country. Many alkali works have been indicted as nuisances on this account. Attempts were made to remedy the evil by discharging the fumes higher in the air, where it was supposed that the great dilution, by combining with atmospheric vapour during their descent, would render them comparatively harmless. This is the origin of those wonderful chimneys, such as that of Muspratt, 495 feet high, and $30\frac{1}{2}$ feet in its lower, and 11 feet in its upper diameter, and containing a million of bricks in its structure; while the chimney of Tennant's soda works at St. Rollox, near Glasgow, is of still larger dimensions. These costly structures have not been found to answer the purpose for which they were intended, so that it has been necessary to condense the gas as fast as it is discharged from the mixture of salt and sulphuric acid.[1] But to return to the decomposing furnace. In about two hours the fumes cease to be copious, and the residuary sulphate of soda becomes a pasty mass. This is now pushed out of the decomposing bed through an opening *a*, in the bed of the furnace, into a vault *v*, which opens into the chimney, so that the workmen are not exposed to the suffocating acid fumes. Another charge is then immediately introduced, and the decomposition goes on as before. The product of the first charge having cooled down, so as not to produce acid fumes, is next shovelled into the other compartment of the furnace nearest the fire, called the *roasting bed* R, where it is exposed to a greatly increased temperature, which in an hour or two dissipates all the remaining muriatic acid. During this operation it changes from yellowish to white. It is now called *salt cake*, and is raked out to make room for another charge.

The object of the next process, which is the most important in the manufacture of soda, is to convert the salt cake or sulphate of soda into carbonate of soda, which is done by heating it to redness, with charcoal and carbonate of lime. By the original method, 100 lbs. of salt cake were mixed with the same weight of chalk and 55 lbs. of charcoal, all ground to a coarse powder, and well mixed by sifting. But as in this country wood-charcoal is too expensive to be used for the purpose, small coal is substituted, and the carbonate of lime may be either in the form of limestone, or chalk. The charge, amounting to 2 or $2\frac{1}{2}$ cwt., is heated in a reverberatory furnace, called the *black-ash furnace;* this is oval in shape, and about 10 feet long in the sole, all corners being avoided, in order that no portion of the charge may escape the action of the fire and the stirring rods. The sole is divided into two parts, one of which, the farthest from the fire, is higher than the other part. The first division is the *preparing bed*, in which the charge is first heated, to avoid cooling the furnace. The second division, called the *fluxing bed*, is slightly concave.

The proportions of the salt cake, coal, and carbonate of lime, as well as the weight of the charge, vary at different works. The charge is shovelled in upon the preparing bed, and spread evenly; when sufficiently heated, it is transferred, by means of an iron tool shaped like an oar, to the fluxing bed, which should be at a full red heat. As soon as the mixture is ignited, and begins to clot on the surface, it is

(1) Patents have been taken out at various times for contrivances for condensing the acid fumes, and converting them to some useful purpose. In one contrivance, the chimney is filled with rounded flints, and in another with coke, kept constantly wet by a small stream of water from the top; and the acid thus condensed by exposure to an extensive humid surface is conveyed along a pipe at the bottom of the chimney, into a subterranean reservoir. In another arrangement, the condenser consists of a series of upright channels or flues, in which the fumes alternately ascend and descend: water falls into these channels from above, and is distributed over boards placed obliquely. Or by another contrivance water is admitted at the bottom of the condenser in the form of a fountain. In some works the acid fumes from the salt, instead of being condensed, are advantageously employed in the manufacture of bleaching powder (chloride of lime); in other works the condensed acid is employed to generate carbonic acid from limestone, for the manufacture of bicarbonate of soda, or of carbonate of magnesia

turned cautiously over by the oar or spreader, so as constantly to expose a fresh surface to the fluxing action of the fire; care being taken not to raise the lighter portions into a dust, or they would be carried away by the draught of the furnace and wasted. When the whole mass has a doughy consistence, chemical decomposition begins; jets of sulphuretted hydrogen, and carbonic oxide, called *candles* by the workmen, escape from various parts of the mass, which is now sedulously worked about with the spreader and an iron rake. At length the mass of soda melts, and from the rapid escape of gas, appears to boil. It gradually settles down, and when all the "candles" have disappeared, the mass is raked out into cast-iron troughs or iron wheelbarrows, where it becomes solid, and forms a mixture of what is called black-ash, with *ball-soda*, or *British barilla.* A second charge is then shifted from the preparing to the fluxing bed, and a third charge immediately placed on the preparing bed. In some large works a ton of the mixture is thus worked off in six hours.

The chemical changes which take place in the above process are somewhat complex, but the most important may be stated thus:—The sulphate of soda, by calcination with the coal, loses its oxygen, and becomes converted into sulphuret of sodium; the carbonate of lime and the sulphuret of sodium then act upon each other, the oxygen of the lime converting the sodium into soda, and the carbonic acid of the lime uniting therewith to form carbonate of soda, while the sulphur of the sodium unites with the calcium of the lime to form sulphuret of calcium.[1] This last-named substance, called *soda waste,* is a source of great annoyance to the manufacturer; it is bulky, and applicable to no useful purpose yet known. Vast heaps of it accumulate in the neighbourhood of alkali works, often making it necessary to purchase land merely to accommodate it. Attempts have been made to recover the sulphur from it, but hitherto the cost has exceeded the value of the sulphur regained.

The next process is to separate the soluble matters from the black ash. A ball of about 3 cwt. as it leaves the black ash furnace, affords an average of $1\frac{1}{4}$ cwt. of soda ash. The insoluble ingredients consist of carbonaceous matters, carbonate of lime, and a compound of lime and sulphuret of calcium. The soluble ingredients are carbonate of soda, a little undecomposed sulphate of soda and common salt, some caustic soda, and a few other ingredients. The separation of these matters is the first step towards the preparation of pure soda from black ash, and this is effected by reducing the mass to fragments, either by crushing it under mill-stones, or by exposing it to the vapour of water, which causes it to swell up and fall to pieces. The fragments are put into iron vats, and covered with warm water. In 10 or 12 hours the solution is drawn off, and the residue washed 6 or 8 times successively, either with fresh water, or with the washings of other vats. The lye thus obtained is evaporated to dryness in leaden pans, (or first in the iron vessel I, Fig. 2003, and then in V,) by which a carbonate of soda is obtained, mixed with a little caustic soda and sulphuret of sodium. This is further purified by mixing it with about one-fourth of its weight of sawdust or coaldust, in a reverberatory furnace, when the sulphuret of sodium parts with its sulphur, and becomes converted into carbonate of soda. In some cases the sawdust or coal is omitted, and the calcination carried on in what is called the *white-ash furnace.* When the liquid assumes the consistence of mortar, it is raked into a large iron vessel, with a false perforated bottom, to allow the mother liquor to drain off from the crystals. The drained mass is then put into a finishing furnace, and moderately calcined, being worked about in all directions, so as to bring every part within the flame, and in contact with air. The residue of this operation when ground under mill-stones, is the *white ash* or *soda ash* of commerce, and is sufficiently pure for most of the manufacturing applications of soda; but for the manufacture of plate glass, and for furnishing crystals of carbonate of soda, the ash is rendered still purer by another calcination at a moderate heat. For the crystalline carbonate, the purified ash is dissolved in hot water to saturation, and the solution run into large cast-iron pans. The soda separates in large well-formed crystals, which are broken up, and the mother liquor allowed to drain off. These crystals are carbonate of soda, nearly pure: 100 parts contain 21·81 soda, 15·43 carbonic acid, and 62·76 water; when exposed to air they fall to powder; boiling water dissolves more than an equal weight of them. The mother liquor which drains off contains nearly the whole of the foreign salts, and is evaporated to dryness: the residue generally contains about 30 per cent. of alkali, and serves the purposes of the crown glass and soap manufacturer.

Bicarbonate of soda, $NaO,CO_2 + HO,CO_2$, is prepared by passing carbonic acid gas into a cold solution of the neutral carbonate, or by exposing the crystals to an atmosphere of the gas. The gas is rapidly absorbed, and the crystals lose the greater part of their water, and become converted into the bicarbonate. It is a crystalline white powder: it cannot be dissolved in warm water without partial decomposition. It is soluble in 10 parts water at 60°, and the liquid has a feebly alkaline reaction, and a milder taste than that of the simple carbonate. By exposure to heat it is converted into the neutral carbonate. *Sesquicarbonate of soda,* $2NaO,3CO_2 + 4HO$, like the sesquicarbonate of potash, cannot be formed at pleasure. It occurs native on the banks of the soda lakes of Sakena, in Africa, whence it is exported under the name of *trona.*

Sulphate of soda, $NaO,SO_3 + 10HO$, or *Glauber Salt,* is a refuse product in several chemical operations. It may be prepared pure by saturating a solution of carbonate of soda with dilute sulphuric

(1) The reactions may be thus represented:—

Sulphuret of Sodium. { Sulphur, Sodium — Sulphuret of Calcium.

Carbonate of Lime { Lime { Calcium, Oxygen; Carbonic acid — Carbonate of soda.

acid. The form of its crystals is derived from an oblique rhombic prism; the crystals effloresce and fuse by heat in their water of crystallization; they dissolve in twice their weight of cold water; at 91·5° Fahr. which is the maximum of solubility, 100 parts water dissolve 322 parts of the salt. If heated beyond this point the solubility diminishes, and a portion of the salt is deposited. This salt has a slightly bitter taste, and is purgative: it is found in some mineral springs, as at Cheltenham. There is a *bisulphate of soda*, containing $NaO,SO_3 + HO,SO_3 + 3HO$. *Hyposulphite of soda*, NaO,S_2O_2, is largely used in photographic processes. [See PHOTOGRAPHY.] It may be found in various ways. According to Fownes, one of the best methods is to form neutral sulphite of soda, by passing a stream of well washed sulphurous acid gas into a strong solution of carbonate of soda, and then to digest the solution with sulphur at a gentle heat during several days. By careful evaporation at a moderate temperature, the salt is obtained in large and regular crystals, which are very soluble in water.

Nitrate of soda, or *cubic nitre*, NaO,NO_5, occurs native in great abundance at Atacama in Peru, where it forms a regular bed, covered with clay and alluvial matter. The pure salt commonly crystallizes in rhombohedrons; it is deliquescent, and very soluble in water; it is used for making nitric acid, and also as a top-dressing in agriculture.

There are several *phosphates of soda;* the common tribasic phosphate, $2NaO,HO,PO_5 + 24HO$, is a beautiful salt; it may be prepared by precipitating the acid phosphate of lime, obtained by decomposing bone-earth by sulphuric acid with a slight excess of carbonate of soda. Its crystals are oblique rhombic prisms; they are soluble in 4 parts of cold water, and the solution is alkaline; the salt is bitter and purgative. Crystals containing 14 equivalents of water have a different form from the above. By adding a solution of caustic soda to the common tribasic phosphate, a second tribasic phosphate, also called *subphosphate*, is obtained. It contains $3NaO,PO_5 + 24HO$. Its crystals are slender six-sided prisms, soluble in 5 parts of cold water, and its solution is strongly alkaline. This salt is decomposed by acids, even by carbonic acid. The effect of heat is to deprive it of its water of crystallization. A third tribasic phosphate, called also *superphospate*, or *biphosphate*, $NaO,2HO,PO_5 + 2HO$, is obtained, by adding phosphoric acid to the ordinary phosphate. *Tribasic phosphate of soda, ammonia and water*, $NaO,NH_4O, HO,PO_5 + 8HO$, has been noticed under its trivial name [See MICROCOSMIC SALT]. It may be prepared by heating 6 parts of common phosphate of soda with two of water, until the whole is liquefied; 1 part of powdered sal-ammoniac is then added; common salt separates, and may be removed by filtration, and the new salt is deposited from the concentrated solution in prismatic crystals, which may be purified by a second or a third crystallization. Microcosmic salt is very soluble. When the salt is gently heated it parts with 8 equivalents of water of crystallization, and at a higher temperature the water in the base is expelled, and also the ammonia; *metaphosphate of soda* remains; it is very fusible, and forms a useful flux in blowpipe experiments. *Bibasic phosphate of soda*, $2NaO,PO_5 + 10HO$, also called *pyrophosphate of soda*, is prepared, by strongly heating common phosphate of soda, dissolving the residue in water, and re-crystallizing. The crystals are brilliant, permanent in the air, and less soluble than the original phosphate. *Monobasic phosphate of soda*, NaO,PO_5, also named *metaphosphate of soda*, is obtained by heating either the acid tribasic phosphate, or microcosmic salt, as already noticed. It is a transparent glassy compound, fusible at a dull red heat, deliquescent and very soluble in water. It does not crystallize, but dries up into a gum-like mass.

Biborate of soda, $NaO,2BO_3 + 10HO$, has been noticed under BORAX.

Sulphuret of Sodium, NaS, may be prepared in the same manner as the monosulphuret of potassium [See POTASSIUM]. It separates from a concentrated solution in octohedral crystals, which are quickly decomposed in the air, into a mixture of hydrate and hyposulphite of soda.

Chloride of Sodium, NaCl, or *common salt*, is the only compound which sodium forms with chlorine. This substance, so important in domestic economy, agriculture and the arts, is very abundant in nature, and exists under various forms.[1] The waters of the ocean contain common salt as their chief saline ingredient, and in countries far removed from the ocean, vast stores of *rock-salt*, or *sal-gem*, exist at a moderate depth beneath the surface. The compound is very stable; it may be fused at a red heat, and on being cooled, concretes into a hard white mass without change. At a bright red heat it sublimes in the air without decomposition, and tinges flame of a blue colour. It is insoluble in alcohol, but dissolves in small quantities in the watery portion of proof spirit. It is scarcely more soluble in hot than in cold water. According to Gay Lussac, 100 parts of water at 58°

(1) Dr. Pereira, in his Materia Medica, has the following observations on the use of salt as a condiment to food :—

"The existence of a greater or less appetite for it in all individuals, appears to me to show that this substance must serve some more important uses in the animal economy than that of merely gratifying the palate. In considering these, we observe, in the *first* place, that it is an essential constituent of the blood, which fluid probably owes some of its essential properties to its saline matter. Now, as the blood is constantly losing part of its saline particles by the secretions, the tears, the bile, &c., the daily loss is repaired by the employment of chloride of sodium as a condiment. In the *second* place, the free hydrochloric acid found in the stomach, and which forms an essential constituent of the gastric juice, is obviously derived from the salt taken with our food. *Thirdly*, the soda of the blood and some of the secretions is doubtless obtained from the decomposition in the system of common salt. These are some (probably only a portion) of the uses which chloride of sodium serves in the animal economy. It deserves especial notice, that while salt is thus essential to health, the continued use of salted provisions is injurious. But their noxious quality is probably to be referred rather to the meat, whose physical and chemical qualities are altered, than to the presence of the salt; though we can readily conceive that an excessive use of salt, or of any other article of food, will be followed by injurious consequences. However relishing salted fish (as anchovies, herrings, cod, &c.) may be, they are difficult of digestion."

dissolve 36 parts of salt; at 140°, 37 parts, and at 225°, which is the boiling point of a saturated solution, 100 parts of water dissolve 40·38 parts of salt. At 32° water dissolves rather more salt than at 60°. According to Fuchs, pure chloride of sodium is equally soluble at all temperatures, 100 parts of water dissolving 37 of salt. The ice, which forms at low temperatures in salt-water, is itself free from salt, a property taken advantage of in some cold countries in the manufacture of salt.[1] Pure salt does not alter by exposure to the air, but as it generally contains minute portions of other salts, which absorb moisture, common salt is usually more or less deliquescent. The form of the crystal, if obtained by slow spontaneous evaporation, is a solid cube, but when procured at a boiling heat from the surface of a solution, the crystals are very small, forming together in groups, so as to present hollow 4-sided pyramids, the sides of which are graduated in steps, as shown in *Fig.* 2004, in consequence of the small lines of cubical crystals gradually retreating inwards. Regnault imagines one of these groups to be formed in the following manner:—Suppose a small cubical crystal to be formed on the surface of the solution; this crystal tends to sink to the bottom of the solution, by virtue of its superior density, but is prevented from doing so by the action of capillary attraction, as shown at *a*, *Fig.* 2005.

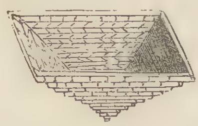


Fig. 2004.

Fig. 2005.

Other crystals are quickly formed around the first, and these attach themselves to the four upper edges thereof, and form a hollow 4-sided frame above the first cube; the group descends in the liquid, as shown at *b*; new crystals form along the upper and outer edges of the first frame, thus forming a second hollow frame as at *c*; another frame forms on the second, and so on, as represented in *d*, and in this way the group enlarges chiefly at the surface of the liquid, which would be likely to be the case, since the salt, being equally soluble, whether hot or cold, does not tend to deposit crystals on cooling, but only on the evaporation of the liquid, which takes place at the surface alone. In the above description it is assumed that only a single row of cubical crystals forms round the outer horizontal edges of the frame previously formed; but it is possible that 2, 3, or 4 rows may be formed in the same horizontal plane, which would be the case if the group did not descend in the liquid as soon as one row of crystals was formed along each of the 4 edges. In this way the heights of the hollow pyramids may vary with respect to the area of their basis, according as the liquid is more or less tranquil, and the capillary action more or less energetic.

The following excellent description of the crystals of common salt is from Bergmann's Chemical Essays:—

"These cubes exhibit diagonal markings or striæ, but frequently on each side produce squares parallel to the external surface, gradually decreasing inwards; circumstances which show the vestiges of their internal structure: for every cube is composed of six quadrangular hollow pyramids, joined by their apices and external surface; each of these pyramids filled up by others similar, but gradually decreasing, completes the form. By a due degree of evaporation it is no difficult matter to obtain these pyramids separate and distinct; or six of such, either hollow or more or less solid, joined together round a centre. If we examine the hollow pyramid[2] of salt farther, we shall find it composed of four triangles, and each of these formed of threads parallel to the base; which threads, upon accurate examination, are found to be nothing more than series of small cubes."

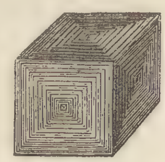


Fig 2006.

The antiseptic properties of salt are not well understood. It is usual to ascribe them to the *drying* influence of the salt. "A dry bladder remains more or less dry in a saturated solution of common salt. The solution runs off its surface in the same manner that water runs from a plate of glass besmeared with tallow. Fresh flesh, over which salt has been strewed, is found after 24 hours swimming in brine, although not a drop of water has been added. The water has been yielded by the muscular fibre itself, and having dissolved the salt in immediate contact with it, and thereby lost the power of penetrating animal substances, it has on this account separated from the flesh. The water, still retained by the flesh, contains a proportionally small quantity of salt, having that degree of dilution at which a saline fluid is capable of penetrating animal substances. This property of animal tissues is taken advantage of in domestic economy, for the purpose of removing so much water

(1) Some experiments by Dr. Faraday show in a remarkable manner how completely foreign substances, such as colouring matter, salts and alkalies, are expelled from water by the operation of freezing. A solution of sulphate of indigo was partially frozen in a glass test tube; for which purpose the tube held in the left hand was moved about in a freezing mixture, while a feather held in the right hand was moved about in the tube, in order to separate the particles of air, and to keep the particles of water, acid, and colouring matter in gentle agitation, so as to assist their separation during the crystallization of the particles of water. In this way the tube was in the course of a minute or two lined with ice, and the whole of the unfrozen colouring matter collected down the centre or axis of the tube: on pouring this off, rinsing the tube with pure water, and taking out the ice, it was found to be perfectly transparent, the whole of the intensely blue colouring matter having been rejected in freezing. Dilute sulphuric acid and dilute ammonia were treated in a similar manner, and the water was frozen, the acid being collected along the central line in one case, and the alkali in the other.

(2) The bases and altitudes of these little pyramids are in general equal: thus showing the disposition of the salt to form a cube.

from meat, that a sufficient quantity is not left to enable it to enter into putrefaction."[1]

Salt, in moderate quantities, is useful as a fertilizer,[2] and, indeed, exists in nearly all soils: it is found in the ashes of all plants, but especially in the ashes of marine plants, and is sometimes borne with the spray of the sea to great distances inland when the winds are strong and the waves high and broken. On some rocky shores, the spray may be seen occasionally moving up the little coves and inlets in the form of a distinct mist, driving before the wind, and the saline matter has been known to traverse nearly half the breadth of our island before it has been entirely deposited from the air. Hence, in those cases in which the use of common salt has failed to benefit the land in particular localities, it must be evident that the soil in these places already contained a natural supply of this compound, large enough to meet the wants of the crops which grew upon it. The influence of the wind in top-dressing the exposed coast-line of a country with a solution of salt, may serve as an important guide, both in reference to the places in which it may be expected to benefit the land, and the causes of its failing to do so in particular districts.[3]

Great Britain, which is so richly supplied with almost every variety of mineral wealth, is furnished with brine-springs and extensive beds of fossil salt. The principal brine-springs are situated in the county of Cheshire, in the valleys through which the Weaver and the small rivulet the Wheelock have their course. The springs do not appear to be strongly impregnated with salt near the source at the Peckferton Hills, nor until the river approaches Nantwich. At this place there are numerous springs from which salt is manufactured. The brine-springs occur at various depths. At Nantwich, the brine is met with about 10 or 12 yards from the surface, and in sinking for fresh water, caution is required to avoid the brine. At Winsford, it is generally necessary to sink from 55 to 60 yards before it is met with, and then it is found in great abundance, and it rises to within 12 yards of the surface. At Northwich it is found at a depth of from 30 to 40 yards, and its level is about 20 yards from the surface. At Wilton, Anderton, and Bampton, the brine is found at depths varying from 40 to 65 yards. The springs along the Wheelock generally occur at greater depths, and are not so copious, some of them being occasionally pumped dry.

The brine-springs appear to have been worked from the earliest periods in the history of this country, but the beds of fossil or rock-salt, from which the springs originated, were not discovered until the year 1670. These were first found about 34 yards from the surface, while searching for coal in Marbury, about a mile to the north of Northwich. The salt was discovered in a bed 30 yards thick, and below it was a stratum of indurated clay. This discovery led to other attempts to find it; and on sinking a shaft anywhere within half-a-mile of Marbury, it was met with at about the same distance from the surface, if the access to it was not prevented by brine or fresh-water. No other rock-salt was discovered till the year 1779, when, in searching for brine near Lawton, it was met with, about 42 yards from the surface. This stratum was only 4 feet in thickness: below it was a bed of indurated clay, 10 yards thick; and in penetrating this, a second stratum of rock-salt, 12 feet in thickness, was found. On continuing the sinking, another stratum of clay, 15 yards thick, was passed through; and below this was a third stratum of rock-salt, which was sunk into to the depth of 24 yards. The lowest, 14 yards, being the purest; these only were worked.

Hitherto no attempts had been made to find a lower stratum of rock-salt in the neighbourhood of Northwich; for as the one first met with was thick, and furnished an abundant supply, there was no inducement to sink deeper. The fear of meeting with springs at a lower depth, which might impede the working of the pits, prevented the attempt; but as no inconvenience of this kind had been experienced at Lawton, where a much purer salt was found at a greater depth than near the surface, the owners of one of the mines near Northwich were led, in 1781, to sink deeper, and to pass through the bed of indurated clay, below the rock-salt which had been so long worked. This clay was 10 or 11 yards in thickness, and immediately below it, was found a second stratum of rock-salt, the upper portion of which differed but little in purity from the higher stratum; but on penetrating into it, from 20 to 25 yards, it was found to be much more pure, and free from earthy admixture. This increased purity, however, was observed for only 4 or 5 yards; the shaft was sunk 14 yards still lower, but the proportion of earth was the same as in the upper part of the stratum. It was, therefore, thought useless to proceed further. Several other proprietors of mines in the neighbourhood also sunk shafts, and obtained similar results.

In sinking for brine or rock-salt, the strata passed through generally consist of clay and sulphate of

(1) Liebig, Organic Chemistry.

(2) Mr. Johnson, in his "Farmer's Cyclopædia," referring to the agricultural uses of salt, laments that during several successive reigns the duty on salt rendered it impossible for the English farmer to become practically acquainted with its value in agricultural operations. The duty originated as a war-tax in the ninth year of the reign of William III. and was not removed until the year 1823. The price of salt in consequence of the duty, was raised from 6*d.* a bushel to more than 20*s.* Salt, as a manure, was therefore known only in the traditions of the English farmers. "Through these they learned that it was formerly used to kill worms and to destroy weeds; that it cleansed fallows, increased the produce of light arable soils, and was good to sweeten grass. These reported advantages were rendered more probable by certain facts that had been forced as it were upon their attention. The gardener was well aware that the brine of the pickling tubs when poured over his heaps of weeds, not only killed every weed, every seed, and every grub, but that these heaps were then converted into so many parcels of the most fertilizing manure; the good effects of which, especially upon potatoes and carrots, were very decided. It was well-known too, that a single grain of salt placed upon an earth-worm speedily destroyed it; that if brine were poured upon the lawn, all the earth-worms were immediately ejected from that spot; and that if it were sprinkled about over a portion of the grass, to this salted portion all the deer, sheep, or the horses of the park constantly repaired in preference to any other part of the field."

(3) Johnston: Lectures on Agricultural Chemistry.

lime (gypsum), mixed in various proportions; that of the latter somewhat increasing as the shaft approaches the brine or rock. The workmen[1] call the clay *red, brown,* or *blue metal,* according to its colour; and the sulphate of lime they name *plaister.* The strata are in general close and compact, allowing very little fresh water to pass through them. In some places, however, they are broken and porous, and admit so much fresh water into the shaft, that whenever this *shaggy metal,* as the workmen call it, has been met with, it has been usual to discontinue any attempts to pass through it. The steam-engine, however, has been since applied to pump out the water, and the workmen have succeeded in sinking shafts through this porous stratum, through the marl and clay below it, and so into the beds of rock-salt.

On making a horizontal section of the bed of rock-salt, various figures may be observed, differing in form and size, some of them being nearly circular, others more nearly oval, and a third set form an irregular pentagon. Some are not more than 2 or 3 feet in diameter, others are 10 or 12 feet. The lines which form the boundaries of these figures are white, and from 2 to 6 inches wide, and consist of pure rock-salt without any earthy admixture. The other portions have earth mixed with the salt in various proportions, and the effect of the whole reminds one of rude mosaic work. This disposition is uniformly observed through the whole thickness of the stratum of rock-salt, wherever a horizontal section is made. The division between the lower portion of the upper bed of rock-salt, and the indurated clay or stone beneath it, is as exactly defined as that between the upper portion of it and the earth above. In passing through this stone, small veins of rock-salt are found here and there, running in it in various directions; and whenever a crevice occurs, this is filled up with rock-salt, to which the clay and oxide of iron have given a deep red tinge. The rock-salt procured from the pits in the neighbourhood of Northwich is from the lower stratum only. The shafts are usually square, and constructed of timber. The rock-salt is obtained in masses of considerable size, differing in form and purity. They are separated by the usual operation of blasting, and with the aid of mechanical instruments. Before extending the workings in any direction, care is taken to secure a good roofing for the cavity which is to be formed. In doing this, the men employ common picks, working horizontally, so as to form a roofing of the rock, and making this as plane as possible. From its situation, (a few feet above the purer part of the stratum,) the rock obtained during this process is usually of inferior quality, and is, for the most part, employed in the refineries. The depth of the workings from the roofings depends, in great measure, on the nature of the stratum, and the proportion of it occupied by the rock of the purer quality; or, as it is termed, *Prussian rock,* from the circumstance of its being largely exported to the shores of the Baltic. The cavity thus formed presents a striking appearance; and when illuminated by candles fixed in the rock, the effect is highly brilliant. In some of the pits the roof is supported by pillars 8 or 10 yards square, which are in general regularly disposed; others are worked out in aisles. The rock-salt is raised to the surface by steam power, but horses are employed underground for conveying the rock to the bottom of the shaft. The men employed in working the rock are paid by the ton, and provide their own tools and gunpowder.[1]

(1) The workmen are called *wallers,* from the circumstance of their raising a bank or a *walling* round the pit with the rubbish of the works.

The brine was formerly raised in various ways: *first,* by pumps worked by hand; *secondly,* in a few situations which admit of the assistance of a stream of water, a water-wheel was employed; *thirdly,* by horse power; *fourthly,* as the demand for salt increased, small windmills were used for raising the brine, and *lastly,* steam power has superseded all other methods of pumping. The reservoirs into which the brine is pumped up are either large ponds formed in clay and generally lined with brick, capable of containing the consumption of several weeks, or they are wooden cisterns pitched within, which will hold a supply of brine for the consumption of a few days only. The brines of the Cheshire springs contain a large proportion of salt, but they are not always completely saturated; and, as it is important not to expend fuel in driving off more water than is absolutely necessary, it is always an object with the manufacturer to obtain a fully saturated brine. This is done by placing a quantity of rock-salt in the cistern, into which the brine is pumped, and allowing the liquor to act upon it until it is saturated. A strong wooden frame is fixed in the cistern at about half its depth, upon which the rock-salt is thrown, and the earthy residuum is occasionally removed from thence, when all the salt has been dissolved.

In the evidence given before a Select Committee of the House of Commons in 1836, Mr. Worthington, a salt manufacturer of Northwich, thus describes the method of getting to the brine:—"We get to the spring by sinking a shaft down to the brine, which is probably a large lake over the body of the salt. There is usually a strong flagstone over the brine. In getting down the shaft to the flag, we form an inner shaft of smaller dimensions in the first one, and fill the space between the two shafts with a puddle of clay, so as to keep what we term fresh water from mixing with that fully saturated body of brine which we expect to find below the flag. After that body of puddle has become solid, the flag is broken, and usually a large supply of brine flows up the shaft, driving the workmen and their buckets before it. This supply of brine has hitherto been exhaustless. When it has been necessary to sink a shaft in a different place, it has been from the circumstance of fresh water breaking through and mixing with the brine, thereby making it of no value. The fresh water being the lightest, remains on the surface

(1) Most of the preceding details are derived from Mr. Henry Holland's "General View of the Agriculture of Cheshire."

in the shaft, and as you pump up one quantity, all the fresh water in the surrounding ground follows, and instead of pumping brine, you pump up much fresh water with it. Fresh water, however, does not get to the great body of the lake."

The brine is drawn from the reservoirs into which it is first pumped, as it is wanted, through wooden pipes or by troughs, into the evaporating pans, fig. 2007. These are made of wrought iron, and contain each from 600 to 1,000 superficial feet. Their usual

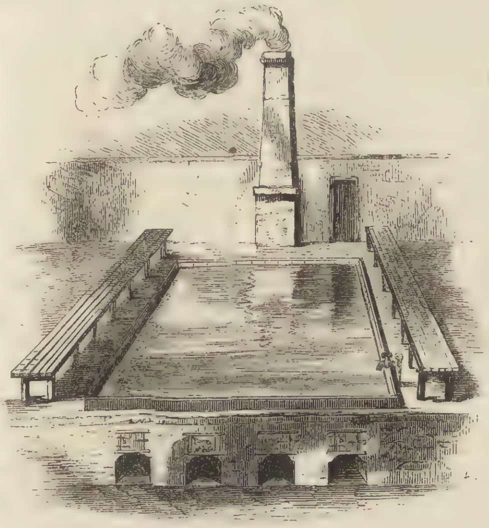


Fig. 2007. EVAPORATING THE BRINE.

form is that of an oblong square, and their depth from 12 to 16 inches. There are 3 or 4 fires to each pan. There is usually a separate *pan-house* to each pan. At one end of this pan-house is the coal-hole, and the chimney at the other end: along each of the 2 remaining sides is a walk 5 or 6 feet wide, and between these walks and the sides of the pan-house, long benches 4 or 5 feet wide are fixed, on which the salt is placed in conical baskets to drain, after it has been taken out of the pan. A wooden or slated roof is placed over the pan-house, with openings to allow the steam to pass freely out.

The process of manufacture in the evaporating pan, varies according to the kind of salt intended to be produced. The perfect crystallization of the salt can only take place under favourable circumstances, such as a freedom from agitation, and the slow and gradual evaporation of the water, which holds the salt in solution; and it is principally on the presence or absence of these causes, that the variation in the appearance of the manufactured salt depends.

To effect the evaporation of the water, heat is applied in various degrees, according to which the product is the *stoved* or *lump-salt; common salt;* the *large grained flaky;* and *large grained,* or *fishery* salt.

In making the *stoved,* or *lump-salt,* the brine is brought to a boiling heat, or 225° Fahr. Crystals of salt are soon formed on the surface, but these subside almost immediately to the bottom of the pan by the agitation of the brine. If taken out, each crystal appears at first sight to be granular or a little flaky; but on closer examination, it is found to approach the form of a somewhat irregular quadrangular pyramid. As the evaporation proceeds, similar crystals form and fall to the bottom. At the end of 12 hours, the greatest part of the water of the brine has evaporated; that which remains being only enough to cover the salt at the bottom of the pan. The fires are then slackened, and the salt is drawn to the sides of the pan with iron rakes. The waller then places a conical wicker-basket or *barrow,* as it is called, within the pan, and having filled this with salt by means of a small wooden spade, leaves it for a short time to allow the brine to drain into the pan, and then carries it to one of the benches at the side, where the draining is completed. It is afterwards dried in stoves, heated by a continuation of the same flues which have passed under the evaporating pan. It loses, in drying, about one-seventh of its weight. In making this salt the pan is filled twice in the course of 24 hours.

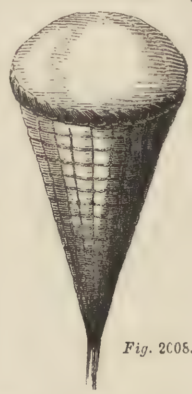


Fig. 2008.

On the first application of heat, if the brine contain any carbonate of lime, the carbonic acid quits the lime, which is either thrown up to the surface when the boiling begins, together with the earthy and feculent contents of the brine, and is removed by skimmers; or it subsides to the bottom of the pan, along with the salt first formed, and with some portion of the gypsum, and is raked out in the early part of the process. These two operations are called *clearing* the pan: some of the brines scarcely require them at all, and others only occasionally. Dr. Henry found these clearings to consist of, in 480 parts, 384 of chloride of sodium, 20 of carbonate of lime, and 76 of sulphate of lime. Circumstances, however, are continually occurring to vary these proportions even in the same brine.

In making the *common salt,* the pan is filled only once in 24 hours. The brine is first brought to a boiling heat, as in making stoved salt, with the double view of bringing it as soon as possible to a state of saturation, and of more readily clearing it of its earthy contents. When these objects have been attained, the fires are slackened, and the crystallization is carried on, with the brine heated to 160° or 170° Fahrenheit. The salt formed in this process is in quadrangular pyramids, or hoppers, close and compact in texture, frequently clustered together, and larger or smaller, according to the temperature employed. Small cubical crystals will often be intermixed with and attached to these. The remainder of the process is similar to that for the stoved salt, except that after draining in the baskets it is immediately carried to the store-house, and not afterwards exposed to heat.

The *large grained flaky* salt is conducted at a temperature of 130° or 140°. This salt is somewhat harder than common salt, and approaches nearer to the natural form of the crystals of chloride of sodium. The pan is filled once in 48 hours. As salt of this grain is often made by slackening the fires between Saturday and Monday, and allowing the crystallization to proceed more slowly on Sunday, when no work is done, but only a man kept to prevent the fires from going out, the salt has hence obtained the name of *Sunday-salt.*

In making the *large grained* or *fishery salt,* the brine is heated to 100° or 110° Fahrenheit, so that the evaporation of the water and the crystallization of the salt proceed more slowly than in making the other kinds; and as no agitation is produced in the brine at this temperature, the salt forms in large cubical crystals, seldom, however, quite perfect. At this temperature, 5 or 6 days are required to evaporate the brine.

In the course of these several processes, various additions are, or were formerly, made to the brine, with the view of promoting the separation of any earthy mixture, or the more ready crystallization of the salt. Animal jelly and gluten, blood, white of egg and glue, have been used. These substances, being mixed with the brine, coagulate with the heat; and in this way entangling the insoluble matters of the brine, gradually rise to the surface, in the form of a thick scum, which being removed, the brine is left clear. In the evidence given before the Parliamentary Committee, in 1835, it was stated that the use of these substances had long been discontinued.

At the time of Mr. Holland's Report, in 1810, *butter* or some other oily substance was generally added to the brine during the evaporating process, and after the clearing, to assist the granulation of the salt, and to make the brine "work more kindly." Its use is as follows:—During the evaporation, it frequently happens that the small crystals of salt which form on the surface of the brine adhere together, and instead of falling to the bottom of the pan, form a kind of crust over a considerable portion of the surface of the brine, thus impeding the evaporation, and, by confining the steam, causing the brine beneath to acquire too high a temperature. When a crust of this kind forms, the salt-boilers say, that "the pan is set over." It is somewhat raised above the surface of the brine, and is usually of an opaque white colour. Now if a very small portion of butter be added to the brine in one of the largest pans, it may be seen in a very few minutes to diffuse itself over the whole surface, and in its progress to occasion any crust which may have been formed on the brine to subside to the bottom of the pan. At the same time a quantity of steam is observed to rise; the superabundant heat is carried off, and the crystallization afterwards proceeds with regularity. Salt-boilers have also been in the habit of adding alum to their brine, when they wish to procure a hard firm salt, of large grain.

But whatever method is adopted to separate the impurities of the brine from the salt, they cannot all be removed from the pan. A portion of these subside to the bottom, and form an incrustation, which the workmen call *pan-scratch,* or *scale;* which, gradually accumulating together with a portion of salt mixed with them, it becomes necessary to remove from the pan every 3 or 4 weeks, by *picking,* that is, by heavy blows with sharp iron picks. Dr. Henry found in 480 parts of these pickings 40 of chloride of sodium, 60 of carbonate of lime, and 380 of sulphate of lime. These proportions, however, are subject to variations in different brines. The pan-scratch accumulates most towards the close of the evaporation; for when there is much salt deposited in the pan, it forms such a heavy mass at the bottom, that the water cannot penetrate into it; and hence the portion which is lowest undergoes a sort of calcination and fusion, which gives it extreme hardness, and a very strong adhesion to the pan.

It was long supposed that British salt was inferior, as a preserver of animal food, to the salt procured from France, Spain, Portugal, and other warm climates, where it is prepared by the spontaneous evaporation of sea-water. Hence large sums of money have been paid every year to foreign nations, for the supply of an article which Great Britain possesses, beyond almost any other country in Europe, the means of drawing from her own internal resources. Some years ago, Dr. Henry instituted a careful inquiry into the subject, feeling how important it was to ascertain whether this preference of foreign salt was founded on accurate experience, or was merely a matter of prejudice; and in the former case, whether any chemical difference could be discovered to explain the superiority of the one to the other.

The result of Dr. Henry's inquiry was, that the slight differences in chemical composition discovered by him in the numerous specimens of salt which he analysed, were scarcely sufficient to account for those properties which are imputed to them, on the ground of experience. The *stoved* and *fishery* salt, for example, though differing in a very trivial degree as to the kind or proportions of their ingredients, are adapted to widely different uses. Thus the large-grained salt is peculiarly fitted for the packing of fish and other provisions, a purpose to which the small-grained salts are much less suitable. Their different powers, then, of preserving food, must depend on some mechanical property; and the only obvious one is the size of the crystals and their degree of compactness and hardness. Quickness of solution, it is well known, is nearly proportional, all other circumstances being equal to the quantity of surface exposed. And since the surfaces of cubes are as the squares of their sides, it should follow that a salt whose crystals are of a given magnitude, will dissolve four times more slowly than one whose cubes are only half the size.

That kind of salt, then, which possesses most eminently the combined properties of hardness, compactness, and perfection of crystals, will be best adapted to the purpose of packing fish and other

provisions, because it will remain permanently between the different layers, or will be very gradually dissolved by the fluids that exude from the provisions; thus furnishing a slow but constant supply of saturated brine. On the other hand, for the purpose of preparing the pickle, or of *striking* the meat, which is done by immersion in a saturated solution of salt, the smaller-grained varieties answer equally well; or, on account of their greater solubility, even better.

The specific gravity of various specimens of salt, which is probably connected with the mechanical property of hardness and compactness of crystals, is almost the same in the large-grained British salt as in that of foreign manufacture. "If no superiority, then, be claimed for British salt, as applicable to economical purposes, on account of the greater degree of chemical purity which unquestionably belongs to it, it may safely, I believe, be asserted that the larger grained varieties are, as to their mechanical properties, fully equal to the foreign bay-salt. And the period, it may be hoped, is not far distant, when a prejudice (for such, from the result of the investigation, it seems to be) will be done away, which has long proved injurious to the interests and prosperity of an important branch of British manufacture."[1]

The most extensive and productive deposits of rock-salt in Europe are those of Bochnia and Vieliczka in Galicia. Numerous other deposits are found along each side of the great Carpathian range, and may be said to extend with greater or less intervals all the way from Moldavia to Suabia. This very extensive tract comprehends the salt mines of Wallachia, Transylvania, Galicia, Upper Hungary, Upper Austria, Styria, Salzberg, and finally of Tyrol. Such deposits form a distinct member in the series of stratified rocks, occurring with limestone, clay, chalk, gypsum, stinkstone, slate, and not unfrequently with bituminous formations. Some geologists suppose that rock-salt has been deposited from saline lakes, or even by the sea, which once covered and afterwards quitted the place. Dr. Macculloch remarks on this hypothesis: "The purity and solidity of the masses of rock-salt, their bulk, their insulated and peculiar positions, with many other facts on which I need not now enter, prove that they could not have been derived from the ocean in the manner thus supposed, nor probably in any manner. They are special and original deposits, in whatever way produced; as of the design we cannot doubt, though no other ends should have been in view than the uses of this substance to man."

The deposits of salt among rocks of almost all ages is an interesting and important fact. Salt is daily accumulating in certain inland lakes and marshes; in Poland it probably exists principally, if not entirely, among tertiary rocks; in the Austrian Alps it is placed in the oolitic system; in Switzerland it is referred to the lias; in Wirtemberg it is in the muschelkalk; in England our greatest salt mines are in the new red sandstone, but there are 2 or 3 copious salt springs in the coal formation, from one of which salt has been largely extracted. In certain parts of the United States salt springs issue from old transition slate rocks; and lastly, a spring containing a great proportion of salt rises near Keswick from the lowest division of the slate rocks of Cumberland.[2]

When a spring during its course comes in contact with a bed of rock-salt, a natural brine well is formed, as already noticed. These wells are seldom so highly saturated as the artificial springs formed by letting fresh water down through a bore to the middle of the salt-bed, and pumping it up again as a saturated solution. Natural salt-wells are usually very slightly impregnated, or they have become weakened by mingling with fresh water after leaving the salt-bed; yet, in many inland situations, where the cost of carriage would make salt a very expensive article, it is found profitable to boil down the weak brine of these springs for the purpose of obtaining salt. In such cases, however, an abundant supply of cheap fuel must be at hand; and even then it would be too costly to conduct the process entirely by means of artificial heat. The greater portion of the water is, therefore, first removed by evaporation in the open air, and the smaller portion of the water is got rid of by boiling.

Now, as the rate at which evaporation proceeds depends upon the amount of surface exposed to the open air, an ingenious contrivance is resorted to in Savoy and Germany, by which the weak brine is exposed to the air in the form of rain, and the action of the air is increased by retarding the single drops as they fall. This plan was first introduced at Moutiers, the capital of the province of Tarentaise, in Sardinia, in the year 1550, for the purpose of obtaining a more economical supply of salt from the neighbouring brine springs of Salins. The plan was first described in England by Mr. Bakewell,[3] from whose account the following particulars are derived.

The salt works at Moutiers are conducted with remarkable economy, and produce nearly three million pounds of salt from a source of water which would scarcely be noticed except for medicinal purposes in any other country. The springs that supply the salt works rise at the bottom of a nearly perpendicular rock of limestone, situated on the south side of a deep valley or gorge, through which the Doron runs before it joins the Isere. The distance from the springs to the salt works is about a mile; the water runs in an open canal made for the purpose, but is received in a reservoir in its passage, where it deposits part of its ochreous contents, and the canal along which it runs is also lined with a red ochreous incrustation. The water rises from the rock with considerable force, and emits much gas, which is principally carbonic, with a mixture of sulphuretted hydrogen; it has an acidulous and slightly saline taste. These springs rise at the end of long passages, excavated in the rock. The temperature of the strongest spring is 99° Fahr.: it contains only 1.83 per cent. of saline

(1) Dr. Henry's Analysis of several varieties of British and Foreign Salt.—*Philosophical Transactions*, vol. c.

(2) Sedgwick and Murchison: Geol. Trans. 1835.

(3) Travels in the Tarentaise. 1823.

matter; other sources contain only 1·50. Besides common salt, the water contains small proportions of sulphate of lime, sulphate of soda, and sulphate and muriate of magnesia, together with oxide of iron.

It may seem remarkable that these waters, which have only half the strength of sea-water, should repay the expense of evaporation. It is obvious that water so weakly impregnated with salt as to contain only one pound and a half in every 13 gallons, could not repay the expense of evaporating by fuel in any country. In order to make salt from this saline water, it was necessary to concentrate it by natural evaporation, and to effect this speedily it was required to spread the surface of the fluid over as large a space as possible, the rate of evaporation being in proportion to the extent of surface exposed to the action of the atmosphere. The first attempt at Moutiers was made in 1550, by arranging pyramids of rye-straw in open galleries, and letting the water trickle through them gradually and repeatedly. By this process a portion of the sulphate of lime was deposited on the straw, and the water became concentrated to a certain degree. It was then carried to the boiler and further evaporated by fuel. In 1730, the present buildings were erected. There are four evaporating houses called *Maisons d'Epines* or *thorn-houses*. Nos. 1 and 2 receive the water from the reservoir, and concentrate it to about 3° of strength, that is, they evaporate one-half of the water they receive. These houses of evaporation are each 350 yards in length, about 25 feet in height, and 7 feet wide. They are uncovered at the top. They consist of a frame of wood composed of upright posts, 2½ feet from each other, ranging on each side, and strengthened by bars across: the whole is supported on stone buttresses about 3 feet from the ground, under which are the troughs for the salt water to fall into. The frame is filled with double rows of fagots of blackthorn, ranged from one end to the other up to the top: they are placed loosely so as to admit the air, and supported firmly in their position by transverse pieces of wood. In the middle of each *Maison d'Epines* is a stone building containing the hydraulic machine for pumping the water to the top of the building; it is moved by a water-wheel. When the water is raised to the top it is received in channels on each side, which extend the whole length of the building; from these long channels it is made to pass into smaller ones by the side, from which it trickles through a multitude of small holes, like a very gentle shower upon the fagots, where it is divided into an infinite number of drops falling from one point to another. Being thus exposed to the contact of the air, it gains one degree of strength in falling, and by the action of the pumps it is raised again, and falls in other showers, till it has acquired the strength adapted to its passing to the evaporating house No. 2.[1]

The process is conducted with less nicety in Nos. 1 and 2 than in the others. The pumps are distributed at equal distances on each side of the thorn wall, and are worked by the machine in the centre of the building. The water is not allowed to trickle down on both sides of the thorns, but only on that exposed to the wind. The two buildings, Nos. 1 and 2, are placed at different angles, to catch the different currents of wind that rush down the valley. No. 3 is constructed on the same principles as Nos. 1 and 2; it receives the water from them both; it is 370 yards long, and is covered to preserve the salt water from the rain. There are 12 pumps on each side of this building, and more care is taken to distribute the water equally: here it is concentrated to the strength of 12 per cent., and deposits most of its remaining sulphate of lime in incrustations on the twigs.

The water being now reduced to about one-seventh of the original quantity, is passed along channels to the thorn-house No. 4. This is only 70 yards in length; here it is further concentrated by a similar process till it nearly reaches the point of saturation, but this depends on the season. In dry weather it is raised to 22°, but in rainy moist weather to 18° only. In summer time, the whole process of evaporation in passing through the different houses, is about one month; in wet seasons it is longer. The stream of water that sets in motion the hydraulic machines for raising the saline water to the top of the building, is brought by a small aqueduct from the river Doron. When once in motion the process goes on and requires little further attention or manual labour till it is completed. When the water is nearly saturated it passes to a large building containing the pans for boiling, and the salt is crystallized in the usual method. The following statement will convey an idea of the quantity of water evaporated before it comes to the pans:—

8,000 hogsheads when received at the evaporating houses, Nos. 1 and 2, contain about 1½ per cent. of salt, and are reduced by evaporation to 4,000 hogsheads.

4,000 hogsheads when received at No. 3 contain about 3 per cent. of salt, and are reduced to 1,000 hogsheads.

1,000 hogsheads when received at No. 4 contain about 12 per cent. of salt, and are reduced to 550 hogsheads.

550 hogsheads received at the pans contain nearly 22 per cent. of salt.

Thus, out of every 8,000 hogsheads passing through the evaporating houses, 7,450 are evaporated by the air in summer, and about 7,000 in winter; and only one-sixteenth part of the fuel is consumed that would be required for evaporating the whole quantity of water by fire.

The fagots are changed at periods of from 4 to 7 years. Those in Nos. 1 and 2, where the saline impregnation is weak, will decay sooner than in Nos.

(1) Mr. Bakewell remarks that this mode of evaporation by the use of fagots was long misunderstood; that it has often been stated by English writers and has recently been again gravely repeated that it consists in throwing salt water upon burning fagots, and gathering the salt that remained. This would be a mode of making salt as wise and practicable as the nursery method of catching birds by putting salt on their tails.

3 and 4. In No. 3 all the twigs acquire so thick a coating of sulphate of lime, that, when broken off, they resemble stems and branches of encrinites.

In the covered house, No. 3, there are 24 pumps—12 on each side—to distribute the water more equally over the whole. This system of pumps is worked by joined bars of wood, which move backwards and forwards, and are connected by crank wheels with each piston to raise and depress it. It has been already mentioned, that care is taken to evaporate on the windward side of the building. When Mr. Bakewell was on the top of No. 3, though the air was very warm, he felt an intense degree of cold, in consequence of the speedy evaporation.

The total length of the *Maisons d'Epines* is as follows:—

Nos. 1 and 2 together	700	English yards.
No. 3	370	,, ,,
No. 4	70	,, ,,
Total	1,140,	or nearly two-thirds of a mile.

The fuel used at the pans for the last process is partly wood and partly anthracite, from the neighbouring mountains. The anthracite answers remarkably well when once ignited, as it preserves, for a long time, a regular degree of heat. The consumption of wood was formerly so great, that it has stripped many of the higher mountains in the Tarantaise, and exposed them to the action of the atmosphere, which has occasioned vast *éboulements,* or mountain slips; for it is found that forests are of the greatest utility in preserving mountains from destruction. The fact is now so well ascertained, that the Government, for this cause alone, have paid particular attention to the preservation of the wood. The quantity of salt made annually at Moutiers is estimated at about 2,250,000lbs., and about 187,000lbs. of sulphate of soda. The other alkaline matter which adheres to the pans is sold to the glass-makers. The Government receives on the average 150,000 francs for the products, out of which it is estimated that 30,000 are expended for wood and fuel, 8,000 for materials employed in the buildings, and for the fagots, &c., and 62,000 for the wages of the different officers; leaving an annual profit of 50,000 francs.

Brine springs are met with at a few places in Saxony; but as they are only slightly impregnated with salt, evaporation by means of fuel would be far too costly a method of obtaining this necessary article of food from them. The method of graduation adopted at Moutiers was introduced into Saxony in the year 1559; and as the plan has, from time to time, received the attention of scientific chemists, it has, in many respects, been improved. We may, therefore, be allowed to introduce a few more details on this interesting subject.

At the Saxon salt-works, the brine is pumped up into a large reservoir, generally placed in a tower, from which it flows into the troughs of the thorn-house. A number of horizontal pipes convey the brine from these troughs *b b*, Fig. 2009, in a thin stream to a perforated channel *c*, from which it falls, drop by drop, upon the wall of blackthorn fagots *t*. A sloping board prevents the wind which passes through the thorns from giving a wrong direction to the falling drops, and the whole is covered with a roof *r*, to prevent rain-water from mingling with the brine.[1] That the air may exert its full effect, the whole structure is erected in an airy situation, and in a direction at right angles to that of the prevailing wind. If the wind changes, and threatens to carry the brine away from the wall, the graduation is reversed to the opposite surface of the thorn-wall, and this is done by moving a lever, whereby certain channels are closed, and others opened, and the brine is carried to the other side, to the opposite surface of the thorns. The brine thus slowly falling and trickling through the thorns, exposes a large surface to a constant current of air, which thus carries off in vapour a considerable portion of the pure water, and leaves the brine, which falls into the lower tank, much stronger than before. The operation is repeated from 3 to 8 times, for which purpose the graduation houses are divided into several compartments, the foremost of which serves for the first fall, the second for the next fall, and so on. At Schönebeck, the surface of the thorn-wall is equal to 390,000 square feet, and this evaporates on an average during the day $3\frac{7}{10}$ths cubic feet of water from each square foot of wall; or in a year of 258 working days, nearly a million and a quarter hogsheads of water. The pumps which serve to raise the brine are usually situated in the central part of the works, and are commonly worked by a hydraulic wheel, as at Moutiers.

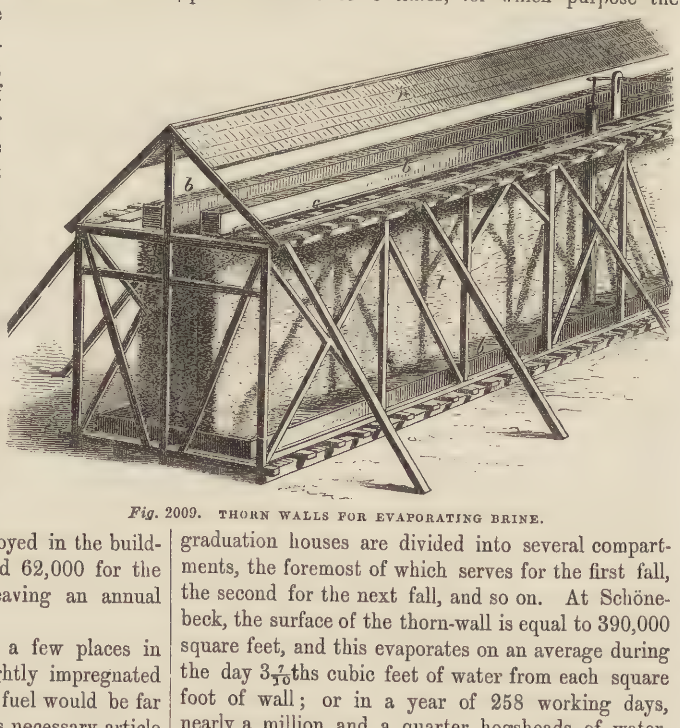


Fig. 2009. THORN WALLS FOR EVAPORATING BRINE.

Previous to the introduction of this plan into Saxony, the graduation was effected by distributing

(1) In the engraving, the greater portion of the roof is removed.

the brine over flat inclined wooden surfaces, or over ropes, stretched backwards and forwards in lengths of many thousand feet. This method is still in use at Moutiers, in addition to the plan already noticed; and during the whole summer, salt was formerly crystallized solely by graduation, without any evaporation by fire. The *Maison de Cordes*, or *rope-house*, was invented by an ingenious Savoyard, named Buttel. It is 40 yards in length, and 11 wide: it is much stronger than the *Maison d'Epines*, the roof being supported by 6 arches of stone-work; the intermediate spaces on the sides being left open. In every one of these divisions are 1,200 cords in rows of 24 each, suspended from the roof, and fixed tight at the bottom. The cords are about 16 feet in length. The water is raised to a reservoir at the top of the building, and distributed in a number of small transverse canals, each row of 24 cords having one of these canals over it, which is so pierced as to admit the water to trickle down each separate cord drop by drop. The original intention of this building was to crystallize the salt itself upon the cords; for which purpose the water was made use of from the pans, after it had deposited a quantity of salt in the first boiling, to save the expense of fuel in a second boiling;—the residue-water of the first boiling, by repeatedly passing over the cords, deposited all its salt in about 45 days, and the cords were incrusted with a cylinder of pure salt, which was broken off by an instrument adapted to the purpose. This process is at present abandoned for crystallizing; but the cords are still used for evaporating, and are found to answer better for the higher concentration of the water than the fagots. This method did not answer for the first evaporation, because the water rotted the cords; but it was discovered, that the cords were not soon injured by it when it had acquired 5° of strength. Mr. Bakewell was informed that the cords at Moutiers had many of them remained 30 years in use without being changed; indeed they were so thickly incased with depositions of gypsum as to be defended from the action of the water. This mode of evaporating is found to be more expeditious than that of the fagots.

In the *Maison de Cordes* it is found that the evaporation goes on more speedily in windy weather than in the *Maisons d'Epines*, as might be expected from the more ready access of air to the surface of the water. The cords are double, passing over horizontal rods of wood at the top and the bottom, to keep them firm in their positions, and at regular distances from each other. The cords are not thicker than the finger, but with the incrustations of sulphate of lime they are often as thick as the wrist.

But to return to the Saxon method of graduation by the use of thorn-walls. Of course the graduation proceeds best with a moderately warm wind and sunshine; a moist calm atmosphere is less favourable to it, and in rainy weather the process is suspended. Very strong winds also occasion inconvenience, by carrying off the brine. Frost is also injurious; for Berzelius has observed, that below 27° Fah. sulphate of magnesia, with a portion of chloride of sodium, becomes converted into chloride of magnesium and Glauber's salt; and that this decomposition is not reversed when the weather becomes warmer. Salt is therefore not only lost in this manner, but the quantity of chloride of magnesium is increased, which is injurious in the boiling process. Graduation is therefore limited to the most favourable portion of the year, including about from 200 to 260 days. It is necessary to regulate the flow of the brine according to the force of the wind; but even with this precaution, there is always considerable loss, from the blowing away of the smaller drops, and also from salt evaporating with the water. That a portion of the salt does evaporate with the water has been proved at the salt-works of Nauheim, where the director, M. Wilhelmi, placed a plate of glass upon a tall pole between two evaporating houses, distant about 1,200 paces from each other, and it was found in the morning, after the drying of the dew, that the glass was covered with crystals of salt on one or the other side, according to the direction of the wind.[1]

In the course of time, the thorns over which the brine trickles become covered with a thick coating of *thorn-stone*, as it is called, consisting of carbonates of lime, magnesia, manganese, and iron, with traces of chlorides. As these deposits gradually fill up the interstices of the thorn-wall, and stop the draught of air, it is necessary to renew the wall every 5, 6, or 8 years. In the brine-cisterns a similar deposit forms like a fine mud, sometimes accompanied by a greyish, thick, scum-like mass, filled with bubbles; this is almost entirely composed of living infusoria, evolving large quantities of pure oxygen.

The progressive evaporation of the water, although varying with the nature of the locality and the state of the weather, may be seen from the following statement, which refers to Dürrenberg.

One cubic foot of brine contains—

In the beginning	2·5 lbs. of salt.
After the first graduation	3·9 ,,
After the second	5·6 ,,
After the third	8· ,,

100 lbs. of salt are therefore dissolved—

In the beginning	in 38·3 cubic feet of water.
After the first graduation	,, 24·7 ,, ,,
After the second	,, 16·6 ,, ,,
After the third	,, 11·3 ,, ,,

For every 100 lbs. of salt are therefore evaporated—

In the first graduation	13·6 cubic feet.
In the second	8·1 ,,
In the third	5·3 ,,

As the evaporation diminishes the loss in graduation increases with the strength of the brine, and, at length, a period arrives when the loss of salt by the wind is equal to the advantage of further evaporation of water. The brine is generally considered fit for boiling when it contains 23 per cent. of salt. If the

(1) Pallas remarked, so long ago as 1770, that in the neighbourhood of the salt lakes of Asiatic Russia, the dew was salt to the taste, and not only the dew which was deposited on plants, but that which collected on smooth surfaces, and even on the dress of persons exposed to it. See the German edition of his Travels, vol. i. p. 426, and vol. iii. p. 635

natural spring contains as much as this, as is the case in some places, the brine is boiled down at once without being graduated.

The brine which is graduated during the fine season, is stored up in vast reservoirs of masonry, covered over and protected from frost. Here the brine makes a further deposit of matters suspended in it. From these reservoirs the pans in the boiling-houses are supplied. The boiling is carried on during the winter months only. Each pan in which the boiler is conducted is a flat four-sided vessel of sheet iron, with a flat bottom, somewhat deepened towards the middle. Some of these pans are as much as 60 feet in length, and 30 in width.

The bottom is supported by brick-work, which contains the flues, which are arranged so as to distribute the flame of two separate fires as uniformly as possible; the flues are also made to heat the chambers where the salt is dried. In order that evaporation may proceed rapidly in the pans, it is necessary for the air to circulate freely above the surface of the liquid. For this purpose each pan is covered with a roof-shaped hood of boards, into which descends a steam or vapour trunk, furnished at the bottom with a number of wooden shutters, which can be turned back or closed as occasion may require. The external air thus passes in a constant current over the surface of the brine, and becoming saturated with vapour, escapes into the chimney. As this vapour contains about one per cent. of salt, means are taken for collecting that portion of it, which becomes condensed, and trickles down the sides of the chimney. This is done by placing, near the bottom of the chimney, a sort of channel connected with a tube leading into a tank. The process of boiling consists of two distinct operations: first, the *schlotage*, or the further purification and evaporation of the brine, up to the point of saturation; secondly, the *soccage*, or crystallization of the salt.

The pans are rather more than half filled with clear brine from the reservoirs, and raised rapidly to the boiling point, the portion which escapes as vapour being replaced from time to time by fresh brine. The surface soon becomes covered with a dirty brown scum, which, with various salts, forms a thick mud. This is partially removed by means of rakes, but a quantity collects on the bottom of the pans, forming what is called *pan-scale*. After 12 or 15 boilings it increases often to the thickness of an inch, and must then be broken up with chisels before it can be removed. The salts in the deposit are chiefly gypsum and sulphate of soda, with a quantity of chloride of sodium; so that these deposits occasion a loss of salt during the boiling.

In the mean time, the solution of salt becomes more concentrated by the constant evaporation and renewal of the brine, until, at last, it crystallizes. A pan containing 1,600 cubic feet of brine, or 176 cwt. of salt, being refilled as often as $\frac{1}{4}$th of the quantity is evaporated, the quantity of salt in the pan after the first addition will be $176 + \frac{176}{4} = 221$ lbs.; after the second addition $176 + 2\,\frac{176}{4} = 286$ lbs. and so on. When, therefore, at the end of 20 or 24 hours, a pellicle of crystals begins to form over the surface, the fire is diminished until the temperature of the brine is allowed to fall to 194° Fahr. and from that to 167°, when, with slow evaporation, the soccage begins and lasts for several days, during which time the small floating crystals on the surface gradually form into four-sided funnels, and soon sink to the bottom by the agitation caused by the escaping vapour. When the pan is kept at a high temperature the crystals have no time to increase in size, and salt of a finer grain falls to the bottom. At the lowest possible temperature they remain floating a longer time, and produce salt of coarse grain. In the former case the process is rapid, in the latter more slow. But neither the process nor the temperature of the soccage are entirely at the command of the workmen, because the chloride of magnesium is always a source of obstruction when little or no sulphate of soda is present. Then two salts mutually decompose each other in the pan, giving rise to chloride of sodium and sulphate of magnesia.

It was observed with the brine from Rodenberg, that the more concentrated brine which contained chloride of magnesium, but no sulphate of soda, became constantly covered all over its surface, at the ordinary temperature of soccage, with a continuous scum of salt which the vapours could neither break up nor pass through, and when removed it was immediately formed again, and thus prevented evaporation from going on. Thus no coarse-grained salt could be produced, and the evil could only be remedied by reducing the temperature, which occasioned loss of time. A remedy was found for the evil by mixing the weaker brine, which contains sulphate of soda but not chloride of magnesium, with the former; but the mixture thus produced contains these two salts, which mutually decompose each other, and produce chloride of sodium and sulphate of magnesia. The result was the same when sulphate of soda was added at once, without diluting the brine by adding the salt in solution. During Sunday, when all work is stopped, *Sunday-salt* is produced by large crystals forming at the bottom; for the salt not being quite so soluble in cold as in hot brine, a portion begins to crystallize as soon as the temperature is lowered, and this attaches itself to the other crystals already in the pan.

The purity of the salt gradually diminishes towards the end of the process. Thus Berthier found in the salt of Moutiers:—

	Salt.	Chloride of Magnesium.	Gypsum.	Sulphate of Magnesia.	Sulphate of Soda.
At the beginning...	94·64	—	1·56	—	3·80
In the middle.......	93·59	0·61	—	0·25	5·55
Towards the end...	85·5	2·0	—	12·5	—

For this reason the soccage must be stopped before all the salt is deposited.

During the whole process of soccage, the salt is

raked up from the bottom with long rakes to the edge of the pan, and placed either in wicker baskets of peeled willow, or heaped upon boards, which are thrown back for the purpose; and in either case, the brine which drains from the salt is allowed to flow back into the pan. The moist salt which remains is conveyed to the drying-room, either in the same willow baskets, or it is spread out upon hurdles, and allowed to remain so long as it loses moisture. It is then packed up for sale.

The salt thus produced is never entirely pure chloride of sodium. It is frequently contaminated with a minute portion of one or other of the following salts:—Chloride of magnesium, chloride of calcium, sulphate of soda, (Glauber's salts,) sulphate of magnesia, (Epsom salts,) sulphate of lime (gypsum). Of all these salts, the chloride of magnesium has the greatest influence on the quality of the produce, on account of its deliquescence in the air, and its highly saline taste. Pure chloride of sodium never attracts moisture from the air; but, when containing only a minute portion of chloride of magnesium, it soon becomes wet in damp weather. Such salt, however, is usually preferred to the purer kinds in places where salt is expensive; because, on account of its pungent taste, a much smaller quantity is consumed. The chloride of magnesium can be got rid of during the soccage by adding slacked lime to the brine in the pan.

After each soccage a quantity of impure brine is left in the pan, which, however, is not rejected after every process. A second, and sometimes a third charge is boiled down before the residue (the *mother-liquor*) is removed. This is a viscous, odoriferous fluid, and may contain the chlorides of calcium, magnesium, potassium, and sodium; the sulphates of magnesia and of lime, and a trace of bromides and iodides. Epsom and Glauber's salts are extensively manufactured from this source, which also furnishes a supply of pure bromine and iodine.[1]

It is an interesting fact, that the plants which generally grow on the sea-shore, such as the *triglochinum maritimum*, the *salicornia*, the *salsola kali*, the *aster trifolium*, or Farewell-to-summer, *glaux maritima*, &c., occur also in the neighbourhood of salt-mines and salt-springs. And the reason for this is, that in such situations they find the food adapted to their habits. "It is thought very remarkable," says Liebig, "that the plants of the grass-tribe fitted for the food of man follow him like the domestic animals. But saline plants seek the sea-shore or saline springs, and the chenopodium the dung-hill, from similar causes. Saline plants require common salt, and the plants growing only on dung-hills need ammonia and nitrates, and they are attracted to places where these can be found, just as the dung-fly is to animal excrements. So, likewise, none of our corn-plants can bear perfect seeds; that is, seeds yielding flower, without a large supply of phosphate of magnesia and ammonia, substances which they require for their maturity. And hence, these plants grow only in a soil where these three constituents are found combined, and no soils are richer in them than those where men and animals dwell together: where the manure furnished by these is found, corn plants appear, because their seeds cannot attain maturity unless supplied with the constituents found in such manure. When we find sea plants near our salt works, several hundred miles distant from the sea, we know that their seeds have been carried there in a very natural manner, namely, by wind or by birds, which have spread them over the whole surface of the earth, although they grow only in those places in which they find the conditions essential to their life.

"Numerous small fish, of not more than 2 inches in length (*Gasterostens aculeatus*), are found in the salt-pans of the graduating house at Nidda, a village in Hesse Darmstadt. No living animal is found in the salt-pans of Neuheim, situated about 18 miles from Nidda, but the water there contains so much carbonic acid and lime, that the walls of the graduating house are covered with stalactites. Hence the eggs conveyed to this place, by whatever cause, do not find the conditions necessary for their development, although they did so in the former place."

The waters of the ocean afford a convenient means for obtaining a supply of common salt to persons situated on or near the coast. The saline matter of sea-water varies from 3 to 4 per cent., and of this quantity, common salt forms nearly two-thirds. The specific gravity of sea-water varies from about 1·026 to 1·030, pure water being 1·000. Many years ago Dr. Marcet made a number of analyses of the water of different seas, and his general conclusions were as follow:—1. That the Southern Ocean contains more salt than the Northern, in the ratio of 1·02919 to 1·02757. 2. That the mean specific gravity of sea-water near the equator is 1·02777, or intermediate between that of the northern and that of the southern hemispheres. 3. That there is no notable difference in sea-water under different meridians. 4. That there is no satisfactory evidence that the sea at great depths is more salt than at the surface. 5. That the sea in general contains more salt where it is deepest and most remote from land, and that its saltness is always diminished in the vicinity of large masses of ice. 6. That small inland seas, though communicating with the ocean, are much less salt than the ocean. 7. That the Mediterranean contains rather larger proportions of salt than the ocean.

The water of the Mediterranean contains in 1,000 parts, according to the analysis of M. Laurens—

	Grains.
Water	959·06
Chloride of Sodium, (common salt)	27·22
Chloride of Magnesium	6·14
Sulphate of Magnesia, (Epsom Salt)	7·02
Sulphate of Lime, (Gypsum)	0·15
Carbonate of Lime	0·09
Carbonate of Magnesia	0·11
Carbonic Acid	0·20
Potash	0·01

(1) For many of the foregoing particulars respecting the manufacture of salt in Germany we are indebted to Knapp's Technology, vol. i. translated by Dr. Ronalds, &c.

There was also a trace of iodine, and of extractive matter.

It may be interesting to compare this analysis with that of the water of the English Channel near Brighton. Dr. Schweitzer found in 1,000 grains of sea-water—

	Grains.
Water	964·74372
Chloride of Sodium	27·05948
Chloride of Magnesium	3·66658
Chloride of Potassium	0·76552
Bromide of Magnesium	0·02929
Sulphate of Magnesia	2·29578
Sulphate of Lime	1·40662
Carbonate of Lime	0·03301

The specific gravity of the water was 1·0274, and it was the same when taken from the bottom of the sea, 10 fathoms deep. The quantity of iodine was very minute; 174 lbs. troy not containing one grain of it. Dr. Schweitzer remarks, that when these analyses are compared, the Channel water will be found to contain 9 times as much lime as the Mediterranean, which is to be accounted for by its flowing over a bed of chalk.

Since the date of these analyses, Dr. George Wilson, of Edinburgh, has discovered that *fluorine* is an element of sea-water. He was led to search for it after observing that fluoride of calcium is slightly soluble in water, which explains its occurrence in springs and rivers. The specimens of sea-water first examined, were taken from the Frith of Forth. Dr. Wilson says, "I obtained the mother-liquor or bittern from the pans of a salt-work there, and precipitated it by nitrate of baryta. The precipitate, after being washed and dried, was warmed with oil of vitriol, in a lead basin covered with waxed glass, with designs on it. The latter were etched in 2 hours, as deeply as they could have been by fluor-spar treated in the same way, the lines being filled with the white silica separated from the glass." Subsequent experiments have abundantly confirmed Dr. Wilson's observations. He had no difficulty in detecting fluorine in the hard crust which collects at the bottom and sides of the boilers used in the evaporation of sea-water at the salt-works. Dr. Forchammer has found in sea-water minute quantities of manganese, ammonia, baryta, or strontia, besides iron and silica.[1]

At one of the meetings of the British Association, Professor Forchammer read a paper, in which he endeavoured to show that in the ocean between Europe and America, the greatest quantity of saline matter is found in the tropical region, far from any land. In such places 1,000 parts of sea-water contain 36·6 parts of solid matter. This quantity diminishes in approaching the coast, on account of the masses of fresh-water which the rivers throw into the sea; it diminishes likewise in the westernmost part of the Gulf stream, where it was found to be only 35·9 in 1,000 parts. By the evaporation of the water of this warm current its quantity of saline matter increases towards the east, and reaches, in N. lat. 39° 39′ and W. long. 55° 16′, its former height of 36·5. From thence it decreases slowly towards the north-east, and sea-water at a distance of 60 to 80 miles from the western shores of England contains only 35·7 parts of solid substances; and the same quantity of salt is found all over the north-eastern part of the Atlantic, as far to the north as Iceland, always at such a distance from the land that the influence of fresh-water is avoided. From numerous observations made on the shores of Iceland and the Faroe Islands, it is evident that the water of the Gulf stream spreads over this part of the Atlantic Ocean, and thus we see that water of tropical currents maintains its character even in high northern latitudes.

The water of the different seas is much more uniform in its composition than is generally believed. The greatest quantity of solid matter ever obtained by the Professor was 37·1 in 1,000 parts, and this was from water near Malta.

It will be seen from the preceding analyses of sea-water, that the quantity of pure water necessary to be evaporated in order to obtain the solid salt, is enormous. The method, however, usually adopted is so economical, that the salt can be sold at a very low price. The sea-water is exposed in a series of shallow ponds to the action of the sun and air, by which means the water is evaporated and the salt deposited in the hindermost pools, whilst the foremost ones are constantly supplied with fresh sea-water. This operation is carried on in what are called *salt gardens* or *salterns*, which are laid out upon a clay soil, on the sea-coast; they are secured from the influence of the

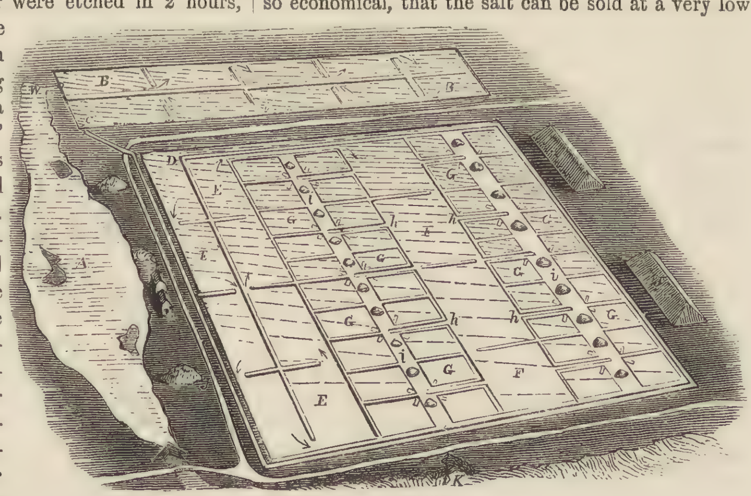


Fig. 2010. SALTERN.

(1) See Dr. Wilson's paper in the Transactions of the Royal Society of Edinburgh, 1846, &c., and in the Edinburgh New Philosophical Journal, 1850, &c.

tides, and are worked during the summer months, from about March to September. The collecting pond A, Fig. 2010, is filled at the flow of the tide through a flood-gate to the height of from 2 to 6 feet. Here the evaporation begins, but the principal object of this first pond is to allow the water to deposit its mud. The clear water is then conveyed by means of a pipe W from the collecting pond to the front pool B, which is quite horizontal, but very shallow. This pool B B is divided into a series of canals by means of a central embankment, and arms proceeding alternately from it, and the sides of the pool. The salt-water meanders slowly from one canal to another in the direction of the arrows, until having arrived at C, it passes along a pipe into a channel which runs along the 4 sides of the saltern, which in that from which the diagram is taken is 16,000 feet long. Having reached D it enters the ponds E E, following the direction of the arrows, and then passing through an open channel it reaches a third series of ponds F F. From F F the brine passes by means of the channels *h h* into the crystallizing ponds G G, where the evaporation is completed. The ponds G G are filled by means of channels at the corners, which can be stopped up at pleasure with a wooden plug. When the brine is admitted into the crystallizing ponds, it is sufficiently concentrated by evaporation during its long transit, to be on the point of depositing its salt. When ready to do so, a reddish tint usually appears in the brine. The salt crystallizes on the surface of the water, and the crust is broken up and collected with rakes into small heaps *i i* on the sides, and from these the mother liquor runs off, and is collected by appropriate channels, and when no more salt separates by crystallization, the lye is allowed to run off through K into the sea. The salt, as at first collected, is too impure for use, the chief impurity consisting of chloride of magnesium: the smaller heaps *i i* are therefore made up into larger square or round heaps J J, which are allowed to remain for a time covered with straw. The rain is thus kept off, and the moisture of the atmosphere suffices to liquefy the chloride of magnesium, which is thus gradually separated from the saline mass.

Although the entire surface of the saltern amounts, together, to many hundred acres, yet the process depends so entirely upon the sun and wind, that in wet weather the evaporation sometimes entirely ceases. At the commencement of the season, 8 days may be required for the deposit of salt in the crystallizing ponds; but in fine weather, and when the brine is properly evaporated before arriving at these ponds, salt is collected 2 or 3 times a-week, and in some cases every day.[1]

Salterns were formerly not uncommon on the coast of Great Britain, and they continued in active operation until the repeal of the duty on salt enabled the Cheshire manufacturers to sell the article at so very low a price, that the proprietors of many salterns could not compete with them. It may however be interesting to notice the method of manufacture formerly adopted at Lymington in Hampshire, as it differs in some respects from the continental plan above described. The sea-water was concentrated, by spontaneous evaporation in the saltern, to about $\frac{1}{8}$th of its bulk, and it was then admitted to the boilers. One kind of salt was chiefly prepared there, which most nearly resembled in grain the stoved salt of Cheshire, and the process for obtaining it varied in some respects from that already described. The salt was not fished out of the boiler and drained in baskets, but the water was entirely evaporated, and the whole mass of salt taken out at once every 8 hours, and removed into troughs with holes in the bottom. Through these it drained into pits made under ground, which received the bittern or mother liquor. Under the troughs, and in a line with the holes, were fixed upright stakes, on which a portion of salt, that would otherwise have escaped, crystallized and formed, in the course of 10 or 12 days on each stake, a mass of 60 or 80 pounds. These lumps were called *salt cats.* They bore the proportion to the common salt, made from the same brine, of 1 ton to 100.

From the mother liquor in the pits, sulphate of magnesia (Epsom salts) was manufactured during the winter season, when the manufacture of salt was suspended. The process was simple. The bitter liquor from the pits was boiled for some hours in the pans which were used in summer to prepare common salt, and the impurities which rose to the surface were removed by skimming. During the evaporation a portion of common salt separated, and this being too impure for use, was reserved for the purpose of concentrating the brine in summer. The evaporated bitter liquor was then removed into wooden coolers one foot deep, where it remained 24 hours, during which time, in clear and cold weather, the sulphate of magnesia crystallized at the bottom, in quantity equal to about $\frac{1}{8}$th of the boiled liquor. The uncrystallizable fluid was then let off through plug-holes at the bottom of the coolers, and the Epsom salt, after being drained in baskets, was deposited in the store-house. This formed *single* Epsom salts, and after being dissolved and crystallized a second time, it was termed *double* Epsom salts: 4 or 5 tons of sulphate of magnesia were produced from a quantity of brine that had yielded 100 tons of common and 1 ton of cat salt.[1]

The simple process of evaporating sea-water on the sea-shore, by means of the sun and the air, in order to obtain a supply of culinary salt, is so obvious that it need not excite surprise that distant nations should adopt similar methods in order to arrive at the same result. Accordingly, we find that salterns are used in some of the islands of the Eastern Archipelago. Sir Stamford Raffles describes the salt manufactories of Java as being important, both with regard to the comforts of the inhabitants, and the interest of the revenue. Nearly the whole of the north-east

(1) Dumas: Chimie appliquée aux Arts, tom. ii.; Knapp's Technology, vol. i.

(1) Dr. Henry: Philosophical Transactions. 1810.

coast of Java and Madura, abounds with places well adapted to the construction of salterns, and unfit for any other useful purpose. The process is simple, and well suited to the people who practise it. On this coast the soil is of a clayey nature, and free from dark loam, which are necessary qualities to the success of the process. The salt-water is admitted through a succession of shallow square compartments, in each of which it receives a certain degree of concentration, until arriving at the last, the water is completely evaporated, and the salt left behind fit for immediate use. The salt thus obtained, though discoloured by admixture with foreign ingredients, is remarkably free from those septic, bitter, and deliquescent salts consequent on a more hasty evaporation. This manufacture goes on during the whole of the dry half of the year. To the success of the operation, it is necessary that the soil should be clayey to prevent the water sinking through; that the shore be flat and extensive, to give easy admission to the brine; and that high mountains should be at a distance, that the process may not be rendered difficult or precarious by the heavy rains that fall in their neighbourhood. It is the absence of this combination of favourable circumstances, that renders the manufacture of salt impracticable in most of the other countries of the Archipelago.

On the boisterous south coast of the island of Java, the shelving nature of the shore, and the porous quality of the soil, will not admit of the cheap process just described. The natives have recourse to another method. The sand on the beach being raked and smoothed into the appearance of ridges and furrows, as if intended for cultivation, the manufacturer, having filled a pair of watering cans from the surge, runs along the furrow, sprinkling the contents in a shower upon the ridges. In a few minutes the powerful effects of the sun's rays have dried the sand, which is then scraped together with a kind of hoe, and placed in rude funnels, over which is thrown a given quantity of salt-water, by which a strong brine is immediately obtained. The peasants convey this brine to their hovels, where it is boiled in small quantities over an ordinary fire, and a salt is obtained, which is necessarily impure, in consequence of the haste with which the operation is performed. This salt costs four-fold as much as the better product of the north coast.[1] It is at the same time inferior in quality, and is only consumed in places which the latter is prevented from reaching by the difficulty of conveyance, or inland tolls and prohibitions; and it has consequently been calculated that the north coast salt, if allowed to pass toll-free through the country, would in a short time supersede that from the south coast altogether. The inferior quality of the latter is caused by the quantity of the sulphate of magnesia it contains, which renders it, by its bitterness, unpleasant for culinary purposes.

The Javanese method of obtaining salt from sea-sand has been practised on the coast of Lower Normandy from the ninth century. The method is the same in principle, although the practice differs. The sand is collected on the sea-shore, where it is left dry by the tide; this is done by means of a long broad scoop, drawn by a horse; the sand is then formed into a kind of filter, through which sea-water is allowed to percolate; this adds considerably to the strength of the sea-water, which is then evaporated in shallow leaden boilers; the fuel is wood; and during the boiling, the scum which rises to the surface is removed. The boiler is filled up many times until a quantity of salt collects in it; the salt is then kept in constant motion by means of long rakes, to prevent the lead from fusing. The evaporation is continued until the salt is dry. In this state it is very impure, and is taken out by means of a perforated tool shown, Fig. 2011, and placed in baskets which are suspended

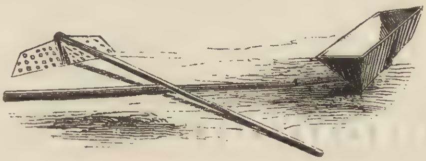


Fig. 2011.

over the boilers, and the steam which rises from them in the next operation of evaporating penetrates the baskets, and washes out a large portion of the bitter deliquescent impurities. The salt is then removed to warehouses, and, with the assistance of the tool shown in Fig. 2011, piled up on the floor, which is formed of a close hard cement. Here the salt parts with another portion of its impurities, and in the course of two months, loses from 20 to 28 per cent. The salt is then very fine and pure, and as white as snow. From 700 to 800 litres of salt-water produce from 150 to 225 kilog. of salt. The lead pans being subjected to this constant heating and cooling, soon become permanently enlarged in size, and require to be frequently reset.

In some parts of Asiatic Russia, advantage is taken of the cold of winter to obtain salt by the congelation of sea-water. The method is founded upon this remarkable property—that when brine is exposed to a temperature some degrees below the freezing point, it resolves itself into two portions, one consisting of pure water, which freezes, and can be removed as solid ice; the other consisting of brine, which does not freeze, but becomes of course intensely salt by the removal of the fresh water. The solid salt is then obtained from the brine by the usual process of boiling.

The salt thus obtained is, however, very impure, unless the precaution is taken beforehand to purify the brine by means of lime. The effect of the low temperature is to decompose a portion of the common salt, and to convert the sulphate of magnesia of the brine into sulphate of soda and chloride of magnesium. In the salt obtained from the brine separated by freezing a portion of water from the sea of Okhotsk, M. Hess found:—

(1) Crawford: History of the Indian Archipelago.

Common Salt	77·60
Sulphate of Soda	13·60
Chloride of Aluminum	6·20
Chloride of Calcium	0·94
Chloride of Magnesium	1·66
	100·00

M. Hess attributes the scorbutic diseases which are so common in the places where this salt is used, to the presence of these chlorides. M. Dumas remarks that this is the first analysis of bay-salt in which chloride of aluminum has been found.

It will be seen from the foregoing details that the collection and preparation of common salt form an important branch of manufacture in different parts of the world. We have noticed the various methods of procuring salt: viz. 1. by mining for rock salt; 2. by pumping up the brine from brine wells, and evaporating it by artificial heat, so as to produce, under certain conditions of temperature, the marketable varieties known as *stoved* or *lump-salt*, *common salt*, *large-grained flaky salt*, *Sunday salt*, *large-grained* or *fishery salt*, &c. 3. Evaporating the brine by the process of *graduation*, as in the thorn-walls, &c., where the brine is weak, and fuel scarce. 4. Evaporating the brine by means of solar heat, as in *salterns*. 5. Saturating the brine by means of sea-sand. 6. Concentrating the brine by the action of a low temperature. Other methods of forming or collecting salt, together with a great variety of particulars respecting the mineral, are given in a work written by the Editor, and quoted below, and to which we are indebted for most of the information to which it refers.[1]

The principal portion of the Cheshire salt, both fossil and manufactured, is sent down the River Weaver to Liverpool for distribution and exportation; only a small proportion being conveyed to other places by canal and land carriage. The white salt made from the Staffordshire springs is chiefly exported from Hull; while that from Worcestershire finds an outlet at Gloucester. In the year 1844, 13,476,884 bushels of rock and white salt were exported, of which quantity—

Russia took	1,823,756	bushels.
Denmark	462,576	,,
Prussia	1,686,520	,,
Holland	799,802	,,
Belgium	1,041,028	,,
Sweden and Norway	237,594	,,
Germany	301,426	,,
British North American Colonies	1,772,799	,,
United States of America	4,664,430	,,
Western Coast of Africa	374,452	,,
New South Wales	125,801	,,
Guernsey, Jersey, &c.	41,032	,,

The remaining quantity was sent in small shipments to the West Indies, ports in the Mediterranean, Brazil, &c. The quantity retained for home consumption in the same year is estimated at 12,647,616 bushels.[2]

(1) "The Natural History of Common Salt: its manufacture, appearance, uses and dangers in various parts of the world." Published (1850) under the direction of the Committee of General Literature and Education, appointed by the Society for Promoting Christian Knowledge.

(2) Porter: Progress of the Nation.

The quantity of salt exported from Great Britain and Ireland in the year 1849 amounted to 18,539,865 bushels, of the declared value of £252,991. Of this quantity, Russia took 2,216,308 bushels, Prussia, 1,231,860; Holland, 941,180; Belgium, 693,537; France, 263,772; Western Coast of Africa, 411,473; British India, 1,195,935; British North America, 2,388,768; United States of America, 7,506,524; Australia, 143,317.

In 1851, salt was exported of the declared value of £224,501; and in 1852, of the value of £236,276.

SOLDER—SOLDERING. Soldering is the art of uniting the edges or surfaces of metals by partial fusion, or by the insertion of an alloy, called *solder*, which is more fusible than the metals to be united. Solders are distinguished as *hard* and *soft*. Hard solders fuse only at a red heat; soft solders fuse at comparatively low temperatures. The metals and the solders which unite them should agree as nearly as possible in hardness and malleability; when this is the case, as when spelter solder is used to unite two pieces of brass or of copper, or one piece of each, or when lead or pewter is united with soft solder, the work may be bent and rolled almost as freely as if it had not been soldered. But when copper or brass are united by soft solder the joint is very liable to be fractured by accidental violence, or the blow of a hammer. In applying the solder, it is of importance that the edges to be united should be chemically clean, and as in this state they have a strong affinity for oxygen, they are protected from the air by means of some flux, which also tends to reduce any portion of oxide left on the parts of the metal to be united. The usual fluxes are borax, sal-ammoniac, chloride of zinc, common resin, Venice turpentine, tallow, and sweet oil.

The hard solders in common use are the *spelter solders* and the *silver solders*. The composition of spelter solders is given under BRASS; they are used for joining iron, copper, brass, gun-metal, German silver, &c. The *hardest silver solder* is composed of 4 parts fine silver and 1 part copper; this is difficult of fusion. *Hard silver solder* is composed of 3 parts sterling silver and 1 part brass wire, which is added when the silver is fused in order that the zinc of the brass may not be burnt out. *Soft silver solder* consists of 2 parts fine silver and 1 part brass wire: $\frac{1}{8}$ part arsenic is sometimes added at the last moment, to make the solder whiter and more fusible; it makes it, however, more brittle, and it is objectionable on account of its very poisonous fumes, which must on no account be inhaled. Silver solders are laminated and used for all silver works, and for common gold work, for German silver, gilding metal, iron, steel, brass, gun-metal, &c. when a neater effect is required than is produced by spelter solder. *White solder*, used as a cheap substitute for silver solder in making gilt buttons, and hence called also *button solder*, and still used for the white alloys called *button metals*, is composed of 10 lbs. tin, 6 lbs. copper, and 4 lbs. brass. The copper and brass are first melted together, the tin is added, and the whole stirred and poured through birch twigs

into water, in order to granulate it; when dry and cold it is pulverized with an iron pestle and mortar. Another button solder consists of 10 parts copper, 8 of brass, and 12 of spelter or zinc. The use of zinc in hard solders is to increase their fusibility; and in cases where the solder cannot be seen, its presence indicates the completion of the process, for when the solder is fused, the zinc becomes volatile, and burns with a characteristic blue flame, while the remaining alloy becomes tougher from the loss of the zinc.

Among the hard solders may also be mentioned *fine gold*, laminated and cut into shreds, and used as the solder for joining the parts of chemical apparatus made of platinum. *Silver* is also used as a solder for German silver. *Copper* in shreds is used for iron, and laminated gold solders are used for gold alloys. The hard solders are also drawn into wires, and filed into dust to suit the magnitude and circumstances of the work.

The soft solder most frequently used consists of 2 parts tin and 1 part lead. A cheaper solder is formed by increasing the proportion of lead; 1½ tin to 1 lead is the most fusible solder, unless bismuth be added. The following table gives the composition of some of these alloys, with their points of fusion:—

No. 1.	1 Tin	25 Lead		558° Fahr.
2.	1 „	10 „		541
3.	1 „	5 „		511
4.	1 „	3 „		482
5.	1 „	2 „		441
6.	1 „	1 „		370
7.	1½ „	1 „		334
8.	2 „	1 „		340
9.	3 „	1 „		356
10.	4 „	1 „		365
11.	5 „	1 „		378
12.	6 „	1 „		381
13.	4 „	4 „	1 Bismuth	320
14.	3 „	3 „	1 „	310
15.	2 „	2 „	1 „	292
16.	1 „	1 „	1 „	254
17.	1 „	2 „	2 „	236
18.	5 „	3 „	3 „	202

If 3 parts mercury be added to No. 18, the alloy will melt at 122° Fahr. and may be used for stopping teeth, and for anatomical injections. No. 5 is the *Plumber's sealed solder*, which is assayed after the manner of pewter, [see PEWTER,] and then stamped by an officer of the Plumber's Company. It is cast in iron moulds into triangular ingots, from 1 to 6 square inches in the section. The fine tin solder is cast into the form of cakes, about 4 inches by 6, and ¼ to ½ inch thick. Both this and the more fusible solders are trailed from the ladle upon an iron plate or a flat stone into the form of bars, ribands, and threads.

The alloy No. 8 is used for soldering cast-iron and steel; the flux used is sal ammoniac, or common resin. The same alloy is also used for tinned iron, with chloride of zinc or resin for a flux. Gold and silver are soldered with pure tin, or with the solder No. 8, and Venice turpentine as a flux. Copper and many of its alloys, such as brass, gilding metal, gun-metal, &c. is also soldered with No. 8, with sal-ammoniac, chloride of zinc, or resin, as a flux; also zinc, with chloride of zinc as a flux. For ordinary plumber's work the alloys from 4 to 8 are used with tallow as a flux. For lead and tin pipes the alloy No. 8 is used with a mixture of resin and sweet oil as a flux. For Britannia metal, No. 8 is used with chloride of zinc or resin as a flux.

The modes of applying heat to the works to be soldered are very various. For hard soldered works the forge may be used. Coppersmiths, silversmiths, and others, use a hearth similar to the blacksmith's, but standing further away from the wall, to allow of the soldering of the central parts of large objects, the bellows being worked by the foot. For large and long works the brazier's hearth is a flat plate of iron, about 4 feet by 3, standing in the middle of the shop upon 4 legs; the fuel is contained in a central aperture, 5 or 6 inches deep, and about 2 feet by 1 foot in area, while the surface of the plate supports tubes and long works over the fire. In some cases the fire extends the whole length of the hearth, or 2 separate fires may be used. A revolving fan is commonly used for the blast, which is directed into the fire by means of tuyeres. A hood is suspended by counterpoise weights from the ceiling, so as to be raised or lowered as required, and it is furnished with sliding tubes for conveying the smoke to the chimney. In some cases muffles or iron tubes are placed in the fire, and in these the articles to be soldered are heated. The best fuel for soldering is charcoal; next to this coke or cinders; coal is injurious on account of its sulphur.

The blow-pipe is also largely used in soldering; but the mechanic commonly uses it in a much rougher manner than the chemist, who excites an intense heat by means of a pencil of flame drawn out silently by air from the mouth, and capable of fusing, oxidizing, or deoxidizing the object of analysis. [See BLOWPIPE.] The mechanic employs a much larger flame than the chemist, such as that from a lamp wick, ¼ inch to an inch in diameter; the blowpipe also has a larger aperture, it is blown strongly, and held a short distance from the flame, so as to spread out a wing of fire with a roaring noise, although in certain cases, as in jeweller's work, where a small portion is to be heated, a point of flame is produced.

The blowpipe flame, as obtained by the blast of bellows with the enameller's lamp, is noticed under ENAMELLING. The manufacturers of cheap jewellery at Birmingham, have a contrivance, represented in

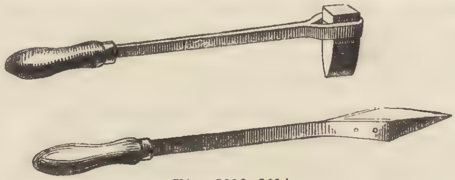
Fig. 2012.

Fig. 2012, in which a stream of air from bellows directs a gas flame along a trough or shoot, placed

at a small angle below the flame. The support is a disk of sheet iron 3 or 4 inches in diameter, mounted on a wooden handle, and covered with a matting of binding wire from ⅜ to ½ inch thick, fastened to the disk by bending some of the wires round the edge. The work to be soldered is placed upon the wire, or upon small cinders supported by the wire, and the flame is thus passed over the work.

In the operation of *brazing*, or soldering with a fusible *brass*, the joints are first secured in their proper position by means of binding wire, the ends of which are twisted together with pliers: the granulated spelter and pounded borax are mixed in a cup with a small quantity of water, and spread along the joint with a small spoon or a slip of sheet-metal. The work is then placed above the clear fire, so as gradually to evaporate the moisture, and fuse the borax, which parts with its water of crystallization, froths up, and then gradually becomes limpid: the solder melts at a bright red heat, as indicated by a slight blue flame from the zinc. The work is then sometimes tapped, to assist the flow of the solder through the joint, but the solder usually *flushes*, or is absorbed by the joint: as soon as this is done the work must be removed from the fire, and when the solder is set the work may be cooled in water. In soldering works in iron, a coating of loam is used to prevent the iron from scaling off. For common works, such as locks, and in soldering the spiral wires which form the internal screw within the boxes of ordinary tail-vices, strips of sheet-brass are used as the solder; and in the last example, as soon as the solder has fused, the box is rolled to and fro on the ground, in order to distribute it equally. The finer works in iron, steel, and brass, are soldered with silver solder, which combines readily with the various metals without wasting the edges of the joints, or, as the workmen term it, without *gnawing* them or *eating* them away. Although this solder is expensive, yet, from the neatness of effect, and the small amount of finishing required, it is really an economical solder. This solder is laminated, cut up into small squares with shears, and put on the joint with forceps. The borax is in many cases previously *boiled* or fused in its water of crystallization, in order that it may not froth up on the work and displace the solder; or the borax may be fused upon the joint itself before the solder is put on. Mathematical and drawing instruments, buttons, jewellery, &c., are supported on charcoal, and soldered with the blow-pipe. The dentists, in soldering the gold work to which artificial teeth are attached, use a lump of pumice-stone as a support, which has the advantage of retaining its form while a charcoal support burns away.

The methods of soft-soldering are various, as may be seen by the variety of fluxes used. The joints of lead-works are first defined by smearing around them a mixture of size and lamp-black, named *soil:* this prevents the solder from adhering to the parts not intended for its reception. The joints are scraped clean with a triangular disc of steel riveted on a wire stem, and called a *shave-hook*, and the clean metal is rubbed over with tallow. In some cases the joints are *wiped*, that is, the solder is heated somewhat beyond its point of fusion, and poured upon the joint in sufficient quantity to heat it: the solder is then smoothed with a cloth made of several folds of thick bed-ticking well greased, and with this the superfluous solder is *wiped* off. In other cases the joints are *striped*, or left in ridges from the bulbous end of the plumber's crooked soldering-iron, heated nearly to redness, and used with the cloth for heating the joint and moulding the solder. For slighter, and neater works, such as lattices, the soldering is performed with the assistance of the *copper-bit* or *bolt*, two forms of which are shown in Figs. 2013, 2014, and consisting of a piece of copper, of from 3 or 4 ounces to as many pounds, riveted into iron shanks,



Figs. 2013, 2014.

and fitted with wooden handles. For works in tinned iron, sheet-zinc, and many of those in copper and other thin metals, this tool, called a *soldering-iron*, is used for melting the solder. For this purpose it is tinned by raising it to a dull-red heat, filing it clean, rubbing it on a lump of sal ammoniac, and then on a copper or tin plate containing a little solder, which, if these operations be quickly done, so as not to cool the tool below a certain point, will adhere to the *iron*, and make it ready for use. When the edges of the work have been brought together they are strewed with powdered rosin, the soldering-iron is held in the right-hand, the cake of solder in the left, and the two are rubbed together, so as to melt a few drops of solder at intervals along the joint. The iron is then applied so as to heat the edges of the joint and to fuse and distribute the solder. The parts are held together by a broad chisel-formed tool, or by a hatchet stake, or the joints may be tacked together at distant intervals by a drop or two of solder; but in many cases the parts are kept together by the hands alone. The tool should be passed once slowly along the work, being guided by the edge or fold of the metal, so as to produce a fine and regular line of solder. Two soldering-irons are generally employed, in order that one may be in the fire while the other is in use. The iron must be made hot enough to raise the edges to the fusing point of the solder, but not so hot as to burn off its own tin coating, or render the solder too fluid. If not over-heated, the *iron* can be used for picking up a bit of solder from the tray in which the cake is fixed in an upright position, and thus a drop of solder can be applied exactly where it is wanted.

The great use of fluxes being to protect the metal from oxidation, to which it is so liable at high temperatures, the choice of the flux is not very important, so that it fulfils this object. It is, however, usual to employ powdered sal-ammoniac with copper works

and those in sheet-iron: rosin and sal-ammoniac are sometimes mixed; and in other cases the edges of the work are moistened with a saturated solution of sal-ammoniac by means of the stubby end of a piece of cane, resin being afterwards used. Chloride of zinc, formed by dissolving zinc in muriatic acid, is an excellent flux, and is well adapted to zinc, which is more difficult to solder than other metals.

The soldering-iron cannot be used when the pieces to be joined are tolerably thick, as in parts of philosophical apparatus, gas-fittings, &c. The parts, being filed or turned, are separately tinned by being dipped into melted solder covered with powdered sal-ammoniac: the work is thus tinned before it has time to become heated. The surfaces, if large, may be tinned by moistening them with the solution of sal-ammoniac, or they may be dusted with the dry powder, or with resin, then heated on a clear fire until a strip of solder, held against them, fuses and adheres. When the parts are properly tinned, they are raised to a heat a little above that required for melting the solder: solder is then applied and properly distributed, and the parts being rubbed together the work is left to cool under pressure.

Small works may sometimes be united by moistening the cleaned surfaces with sal-ammoniac water, or by the application of resin, and then placing between them a slip of tin-foil cleaned with emery-paper: on pinching the whole together between a pair of heated tongs, the foil will melt. The blow-pipe is also used in many cases of soft-soldering. The gas-fitters use the blow-pipe in joining tin and lead pipes: they do not employ the *spigot-and-faucet* joint with a bulb of solder round it, but cut off the ends of the pipes with a saw, and file the surfaces intended to meet in butt joints, in mitres, or in T-formed joints, as required. They use a rich tin solder, with oil and resin mixed in equal parts as the flux. Mr. Holtzapffel remarks, that the work looks more like carpentry than soldering.[1] The gas-fitters and pewterers employ a *portable-torch,* made of 3 or 4 dozen rushes, with only a slight coating of tallow, and retained in a paper-sheath. The pewterers have a kind of blow-pipe or hot-air blast, consisting of a common cast-iron pot *h*, Fig. 2015, with a close cover, containing ignited charcoal, and termed a *hod:* it has a nozzle *b* leading into it, which supplies air from bellows worked by the foot, and another nozzle *n*, which directs the current of hot air upon the article to be soldered. This is placed upon a support *g*, called a *gentleman,* which admits of being adjusted to the required height by a side-screw. The strip of solder is dipped into oil and applied to the joint with the right-hand, while the work is slowly turned round with the left. The solders used by pewterers are termed *hard-pale, soft-pale,* and *middling-pale.* The first corresponds with No. 8, in the list of solders. The soft-pale contains 2 parts tin, 1 of lead, and 1 of bismuth.

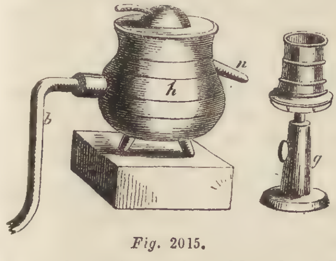


Fig. 2015.

(1) In the first volume of the "Mechanical Manipulation" is an excellent chapter on "Soldering."

For certain works a method of soldering, termed *autogenous,* and also *burning together,* has been introduced, in which neither solder nor flux is used, the intermediate metal being identical with that whose edges are to be joined. The objections to solder in many cases are that it contracts and expands under the influence of heat differently from the metals which it unites, and thus is liable to produce a leaky joint. It is also more readily attacked by acid and corrosive substances; and in consequence of the formation of voltaic currents it oxidizes more easily. Hence in the leaden chambers and vessels used in the manufacture of sulphuric acid, autogenous soldering is of importance. Pewter is also in some cases burned together at the external angles, in order that no difference of colour may exist. Brass is also burned together, as noticed under CASTING and FOUNDING; and indeed the method of burning is used for most of the metals and alloys in making small additions to old castings, and in repairing holes and defects in new ones.

In the practice of autogenous soldering, the *airo-hydrogen blowpipe* invented by the Count de Richemont is useful. It is a contrivance for a jet of mixed hydrogen and atmospheric air, which on being ignited produces a considerable heat. The hydrogen is supplied by a reservoir H, Fig. 2016, which is filled with shreds of zinc through an opening at the top, and is then closed by the screw stopple *s*. Sulphuric acid diluted with 6 times its bulk of water is poured into the upper vessel V, through a hole *h* in the centre of

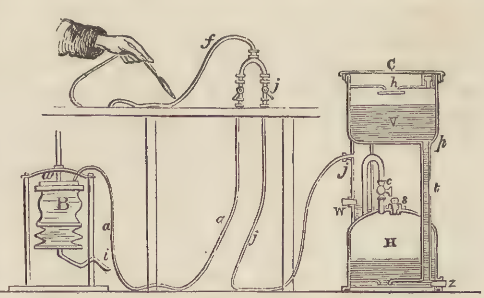


Fig. 2016.

a diaphragm placed a little below the cover C; and when the acid solution just covers the plate below the hole *h*, a sufficient quantity has been poured in to charge H without risk of overflow. From the bottom of this vessel a tube *t*, passes to the bottom of the vessel H: this tube is closed at its upper extremity by a stopple at *p*, attached to a wire extending through the diaphragon. On pulling up this stopple a portion of the acid solution descends into H, and expels the air from it through the stopcock and chamber C, and along the jet pipe *j j*, the stopcocks *c* and *j* having been left open for the purpose. These stopcocks being closed, hydrogen gas accumulates in H, and by its

pressure forces a portion of the acid solution up the tube *t*, and back into V, and thus suspends or greatly diminishes the generation of gas. When the hydrogen is required for use the stopcock *c* is opened, and the gas passing through the siphon-tube bubbles through water W in which the lower end of the siphon-tube is immersed, and thus escapes into the safety box, into which one end of the jet tube *j* is inserted. The use of this safety box is to prevent the return of the flame into H, in which case, if air were left in H mingled with the hydrogen, an explosion might ensue. The safety box is supplied with water through the aperture W. After 3 or 4 days' constant use the liquid becomes converted into a solution of sulphate of zinc, which is drawn off through the aperture *z*, which at other times is kept closed with a stopple. Atmospheric air is supplied to the apparatus by means of a small pair of double bellows B, worked by the foot of the operator at *i*, and compressed by a constant weight *w*. The air proceeds along the air jet pipe *a*, and meeting the hydrogen at the point where the two pipes unite in an arch, the mixed gases proceed along the jet pipe *f* to a jet which is ignited, held in the hand, and applied to the work. The various connexions are made by elastic tubes of varying lengths, so as to allow of perfect freedom of motion. The gas generator is made of lead, or of copper washed with lead, and all the exposed parts of the brass work are washed and united with lead to protect them from the acid.

In soldering by this method the works are scraped clean, the hydrogen is ignited, the magnitude of the flame being regulated by opening the stop-cock *j* more or less; air is then admitted through *a*, and when the flame is pointed and well-defined it may be used as a blowpipe flame, a strip of lead being used instead of solder, and fluxes seldom employed. In plumber's work, to which this method is well adapted, the weight of lead consumed in making the joints is a mere fraction of the weight of ordinary solder. Moreover, from the absence of fluxes the work is more under the eye; for fluxes, such as resin, often conceal fractures and bad joints, and the solder often sticks to the lead without being fused into it. Moreover, this method of *gas-soldering* is less dangerous than the ordinary method, the plumbers not having to take their fires upon roofs and among timbers, by which accidents have occurred, and many a noble building has been consumed; but the gas generator may be left on the ground while the man ascends to the roof with the pipe.

The gas flame may also be used for heating the copper soldering tool, Fig. 2017, and keeping it at

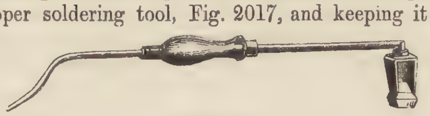


Fig. 2017.

one temperature, for which purpose the gases are conducted through a tube in the handle, and the flame plays on the back of the copper bit.[1]

SOLUTION, an important process in chemical operations, the objects of which are to prepare substances for the exertion of chemical action, by separating the particles, and destroying the attraction of aggregation; and, secondly, to separate one substance from another, by employing such fluids as have a solvent power over one or more of the substances present.

Solution is of two kinds: in the one the fluid, or *menstruum* producing the solution, has no chemical action on the substance dissolved; in the other, such an action does take place. "Water is the great solvent, whose aid is to be first called in: other fluids are to be resorted to only when that is insufficient. So general and important is its use, that in speaking simply of the solubility of a body, water is always understood to be referred to. All aqueous solutions of solid bodies are heavier than water; upon this difference is founded a very convenient indication of solubility, frequently useful, always easy. It is to suspend a piece of the substance in a glass of undisturbed water: if the body be soluble a descending current will be seen to fall from it, and be visible upon looking through the water horizontally. If it fall rapidly, and in dense striæ, it will indicate rapid solubility and the formation of a dense solution; if it fall in a very narrow stream, it will indicate only moderate or slight solubility; and by its descending rapidly, or in a slow broad stream, or by resting about the substance, a judgment may be made of the comparative density of the solution produced. If no descending current appear, nor any fluid round the substance of a refractive power or colour different to that of the water, then the body must be very nearly, if not quite, insoluble at common temperatures.[2]

The saliva of the mouth having nearly the same solubility as water, the taste of a substance may afford an indication of its solubility; those substances which are most sapid being, generally speaking, most soluble.

Water does not dissolve the resins; oils do not combine with it, and it does not dissolve any one of the metals. It dissolves the *oxides* of the metals of the alkalies, such as potash and soda. Resinous bodies are soluble in alcohol; caoutchouc in ether, naphtha, and turpentine. "If a substance appear to be insoluble, or if it be necessary to know whether it be soluble in alcohol, ether, oils, or any other body, for the purpose of selecting a solvent from among them, a portion should be pulverized finely, and introduced into a small tube, with a little of the fluid to be tried, and heated. If the substance disappear, it is, of course, soluble; but if it be supposed to be a mixed body, and partly soluble, though not altogether so,

(1) Richemont's claim to the invention of autogenous soldering has been disputed. We are informed that, previously to the year 1833, Mr. Mallet employed an apparatus on the same principle as Richemont's, and used it in a similar manner. The late Professor Daniell, of King's College, also claimed the invention; so did Mr. Loudon, and also Mr. Thomas Spencer, of Liverpool, whose paper "On the theory and practice of soldering metals" was read before the Liverpool Polytechnic Society, in May 1840, and published in the *Mechanics' Magazine*, vol. xxxii.

(2) Faraday, "Chemical Manipulation," Sec. vi. In Regnault's "Cours de Chimie," tome ii., is a valuable article on the "Solubility of Salts."

then the presumed solution should be poured from the tube into an earthenware or platina capsule, and evaporated carefully and slowly; if any substance remain, it of course indicates solubility. Trials by evaporation cannot be made with oil, unless the body be fixed, and will allow the oil to be burned off; nor can trials of very volatile bodies be made in this manner."

When solution is brought about by chemical action, the substance is changed in appearance. "A body not soluble in water, except by the use of acids or alkalies, is generally, though not always, rendered so by chemical action." The metals are insoluble in any solvent until they have undergone some change by its action. Thus, when copper is put into nitric acid a portion of the acid is decomposed, the copper becomes converted into an oxide, which is soluble in the acid, and thus a salt is formed, viz. nitrate of copper, or, more properly, nitrate of the oxide of copper. If it be desired to know whether one liquid is soluble in another, a portion of the most valuable is put into a tube, and a small quantity of the other added to it: the tube is then to be shaken, and allowed to repose, when it will be seen if the two have permanently mixed, or whether they separate. Should they separate, an additional quantity of the required liquid is to be added, agitated, and observed as before; and this process should be continued until the two liquids form one homogeneous liquid, or the added portions remain unmixed. The results will indicate the degree of solubility. The solution of certain gases in water is generally conducted in a Woulfe's apparatus, shown in Fig. 717.

The dissolving power of a liquid is, in most cases, greatly heightened by raising the temperature. Lime and magnesia are exceptional cases, these bodies being more soluble in cold than in hot water; and common salt may perhaps be cited as another exception to the rule. Sulphate of soda is more soluble in water, at the temperature of 91·5° Fahr., than at a higher or a lower point. Gases are also more soluble in cold than in hot water. A body not soluble at common temperatures, is not made so by the mere application of heat. Comminution also greatly assists solution.

SOLVENT. See SOLUTION.

SOOT consists chiefly of carbon in a pulverulent form, condensed from the smoke of wood or coal fuel. The soot of pitcoal contains sulphate and carbonate of ammonia, and some bituminous matter.

SORBIC ACID. See MALIC ACID.

SPAR (German *Spath*), a term which, in combination with specific terms, includes various crystallized earthy and some metallic substances. Thus, *calcareous spar* is crystallized carbonate of lime; *Derbyshire* or *fluor spar* is fluoride of calcium; *heavy spar* is sulphate of barytes.

SPECIFIC GRAVITY. See GRAVITY SPECIFIC—HYDROSTATICS, AND HYDRODYNAMICS.

SPECIFIC HEAT. See HEAT.

SPECTRUM. See LIGHT—PHOTOGRAPHY.

SPECULUM METAL. See CASTING AND FOUNDING.

SPELTER. See ZINC.

SPERMACETI. See WHALE OIL.

SPIKE. See LAVENDER.

SPINNING. See COTTON—FLAX—SILK—WOOL.

SPIRIT-LEVEL. See LEVEL.

SPIRITS OF WINE. See ALCOHOL.

SPONGE. See INTRODUCTORY ESSAY, p. cxxviii.

SPRING. See BALANCE—HOROLOGY—WHEEL-CARRIAGE—RAILWAY, &c.

STAINED GLASS. See GLASS, Sect. IX.

STAMPED WORKS. See RAISED WORKS IN METAL.

STAMPING MILLS. See METALLURGY.

STARCH is an important element of food, not only of animals but of vegetables. Liebig says, "Its ready convertibility, without change of composition, into soluble forms, such as dextrine and sugar, adapts it admirably for carrying on those changes which occur in the juices of vegetables. It is stored up in the seeds, roots, and pith of plants, and by its decomposition furnishes the materials for many of the most essential vegetable products. It also serves as a most important element of the food of animals, furnishing not indeed the means of increase of mass, but the materials for keeping up respiration and supplying the animal heat. The fats and fixed oils of the vegetable as well as the animal kingdom, are in all probability derived principally from the deoxidation of starch."

Starch is one of the most abundant constituents of vegetable principles. It exists in the seeds of all acotyledonous plants; in many perennial roots which produce an annual stem; in tuberous roots; in the stems of many monocotyledonous plants, as in those of the palm tribe; in unripe apples and pears, and also in lichens. It is seldom found in the stems and branches of dicotyledonous plants. Starch is contained in plants in the cavities of the cellular substance, not attached to the cell, but surrounded with an aqueous liquid.

Starch, from whatever source, always presents the same *chemical* characters: its *physical* characters, however, may slightly vary with the plant which furnishes it, and the processes followed for obtaining it. In its pure state it is a fine, white powder, without taste or smell. It emits a peculiar sound when squeezed between the fingers; it feels slightly crystalline, *tous les mois* and *potato*-starch more so than the other varieties. Starch is not soluble in cold water, in alcohol or ether. It forms with boiling water a kind of mucilage which cools down into a jelly. It is soluble in dilute acids, forming a transparent solution, which undergoes a series of remarkable changes by boiling [see BEER]. The recent solution forms a deep blue with an aqueous solution of iodine; but after boiling for a short time the colour is purple; and by continuing the boiling, iodine does not produce any colour, in consequence of the formation first of dextrine and then of sugar. Starch forms a transparent gelatinous compound if rubbed up in a mortar with a strong solution of potash, which compound is soluble in water and in alcohol;

and the addition of acids produces a precipitation of the starch. Dried at 212°, starch was found to consist of carbon 44·44, hydrogen 6·17, and oxygen 49·39. At common temperatures starch is represented by the formula $C_{12}H_{12}O_{12}$: so that by being raised to the temperature of 212°, it loses two equivalents of water. The sp. gr. of ordinary starch is about 1·5.

The usual sources of the starch used in the arts are 1, *wheat* and the grains of *cereals*, which produce *common starch;* 2, the tubers of the *potato*, which furnish *potato starch;* 3, *arrow-root*, from the roots of the *maranta arundinacea;* 4, *East India arrow-root* from the tubers of the *curcuma angustifolia;* 5, *sago*, from the pith of palms of the genus *sagus;* 6, *cassava* and *tapioca*, from the tuberous root of the *jatropha manihot;* 7, *Indian corn* (*zea mais*); 8, *salep*, probably from the roots of different species of orchis; 9, *Tous les mois*, probably from *canna coccinea;* and 10, *rice*, which furnishes *rice starch.*

Starch has an organized structure: when examined by the microscope, it presents the form of rounded grains, the size and shape of which differ in the starch of different plants, and also in that of the same plant at different times, and from different parts of the same plant at the same time. Thus the diameters of the granules of potato-starch vary from $\frac{7}{1000}$th to the $\frac{2}{100}$th of an inch. The granules of starch from wheat are more regular in form than those from the potato. The size of the granules increases with the age of the vegetable, and in certain organs the shape also changes. Each granule of starch has an outer envelope, differing in its characters from the globule which it encloses; or rather, the granule consists of concentric layers of unequal thickness. The interior and exterior are both insoluble in cold water, or so little soluble that 1,000 parts of water are required to dissolve one part of starch. On rubbing the granules in a mortar with sand, the envelope is broken, and the interior exposed. On putting the mixed powder into cold water, it swells up into a tremulous jelly, but does not dissolve more than in the above very limited proportion. Or if the granules be not bruised, but be simply mixed with water at the temperature of 140° Fahr., they imbibe water, swell, burst their envelopes and form a jelly, which, however, is not regarded as a solution of starch, any more than the water sucked up by a sponge is regarded as a solution of that substance. If the starch jelly be placed on filtering paper, it parts with its moisture and dries up into a horn-like substance insoluble in cold water. This gelatinous starch is termed *amidin.* It is soluble in boiling water, and a strong solution, on cooling, will deposit much of the starch in a gelatinous state. When a solution of starch is frozen, amidin separates from the water and contracts into a kind of tissue, which does not dissolve when the ice is thawed. When starch is boiled in water, a tegument is formed which dissolves on continuing the ebullition: this tegument amounts to about 3 or 4 parts in 1,000 of the starch.

The granules of some varieties of starch appear under a high magnifying power to be marked on their surface with eccentric rings surrounding a well-defined point, as shown in some of the varieties of starch in Fig. 2018. Raspail regards these wrinkles as affording indications of a spiral attached to the interior of the tegument, and proceeding from the

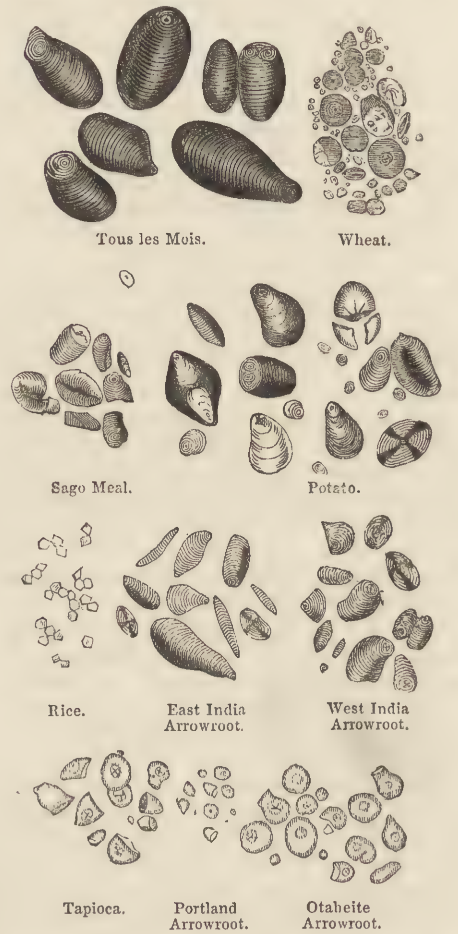


Fig. 2018. MICROSCOPIC REPRESENTATIONS OF DIFFERENT VARIETIES OF STARCH.

point or *hilum.* M. Fritzsche considers them to afford evidence of the concentric layers. The hilum is probably an aperture leading into the interior of the granule, by which the amylaceous matter which forms the internal laminæ is introduced.

When granules of starch are distended by moisture, they display the phenomena of double refraction in consequence of the pressure exerted by the teguments upon their contents. When put up in Canada balsam or in water, and viewed in a microscope by polarized light, a black cross is observed (such as is exhibited under similar circumstances by doubly refracting crystals) when the planes of polarization of the *polarizer* and *analyser* are at right angles to each other.[1]

(1) The *polarizer* is a Nicholl's prism, or a tourmalin placed beneath the stage on which the object is placed: this polarizes the light reflected through the object by the mirror attached to the microscope. A second Nicholl's prism or tourmalin, attached to the eye-piece of the microscope, forms the *analyser.*

The black cross is shown in some of the varieties of starch in Fig. 2018. Its centre is at the hilum of the granule : the other portions of the granule are white, but the field or ground is black or grey. On turning round the analyser or the polarizer 90°, the black cross is replaced by a white one—the other parts of the granule become dark and the field white. If a thin plate of mica or of selenite be placed between the eye and the reflector, the edges of the cross and the intervening spaces become coloured, and the field assumes a tint depending on the thickness of the plate of mica or of selenite. The colours of the adjoining spaces on either side of the cross are complementary to each other, and they change on revolving the analysing plate at every quarter of a revolution. These beautiful effects are produced by all the varieties of starch, but with greater or less distinctness, probably depending on the state of distension. They are better displayed in tous les mois, potato starch, and Indian corn starch, than in wheat, barley, and some other kinds of starch.

If starch be dissolved in hot water, and the solution, when cool, filtered through paper, a precipitate is thrown down by the addition of alcohol; the structure of the precipitated granules appears under the microscope to be spherical, and the size of the granules is less than $\frac{1}{10000}$th inch. If starch be heated for about two hours with from 5 to 15 parts of water, under pressure to the temperature of 150° cent. (302° Fahr.) it dissolves entirely, except the outer coating, and the solution, if nearly boiling, can be filtered through paper. The liquid, on cooling, deposits a considerable quantity of starch in white granules, opaque in the mass, and denser than water. When dry this deposit is white, but without the lustre of common starch. The increased solubility thus conferred upon starch, is a remarkable fact. The granules are composed of $C_{12}H_{10}O_{10}$, as in starch dried at 212°.

In the manufacture of starch by the ordinary processes, wheat is preferred to any other material. Sir H. Davy found as much as 76·50 per cent. of starch in a sample of Middlesex wheat; 75 per cent. in Polish wheat; 73 per cent. in North American wheat. Even such wheat as is damaged by exposure or long keeping will serve for making starch,—this principle being much less liable to decomposition than the other constituents of wheat.

The simplest method of separating the starch from the gluten and the other constituents of wheat, is by the process noticed under Bread, viz. that of washing dough in a linen bag in a gentle stream of cold water. By this process, however, the starch is not entirely free from gluten: a plan is therefore adopted, founded on the property which dilute acetic acid, or a dilute alkaline solution, has of dissolving gluten, and not acting on the starch. The alkali, caustic soda, is specially added by the manufacturer in making starch from rice flour; the acetic acid is not added, but is generated by the fermentation in the liquor, and consequent decomposition of a portion of the gluten and of the starch. This takes place when wheat is used, and for the purposes of manufacture the grain is coarsely ground between iron rollers, and digested in a vat with water enough to wet it thoroughly. In 3, 4 or 5 days, according to the weather, fermentation sets in, the mixture settles, and is removed to a large fermenting vat with more water. There it remains for 2 or 3 weeks, when the deposit is removed to a stout basket, and washed by a stream of water, with constant stirring. The bran is left in the basket, and the milky liquor which passes through contains the starch; it is strained through a hair sieve into a square tub or *frame*. In about 24 hours the impure starch subsides; the supernatant liquor is withdrawn by taking out plugs situated at different heights in the side of the frame. The deposit consists of an upper layer of thin, light, mucilaginous matter called the *slimes*, below which is a white coherent layer of impure starch. The slimes are removed, and the remainder being agitated with fresh water, is thrown upon a finer sieve than that previously used. When the starch is deposited from the strained liquid, the latter is decanted off; the second slimes are removed, and the starch is again agitated with water. Having been again passed through a sieve it is left for several days, in order that the deposit of starch may become firm. A little smalt or artificial ultramarine is added to give the blue tint, and any trace of acid must be neutralized by the addition of an alkali. Indeed, it is an advantage to leave the starch slightly alkaline, since the liability to fermentation in a damp place generates acetic and perhaps lactic acid in the starch, the effect of which is to weaken the fibres of clothes containing the starch. When the starch is sufficiently firm, and while still moist, it is *boxed*, that is, it is shovelled into oblong wooden boxes 4 to 5 feet long, 1 foot broad, and about 6 or 7 inches deep, perforated at the bottom and lined with linen cloth or fine canvass. When tolerably hard the starch is taken out, cut into pieces, 5 or 6 inches square, and set to dry on half-burned bricks, which by their porosity absorb moisture from the starch. They are left in this condition for 8 or 10 hours, and then placed in a hot room or *stove* fitted with racks for holding the pieces of starch. When tolerably dry the pieces are removed to a table, and a slimy crust which forms on the sides is scraped off with a knife. The remainder, or pure starch, is packed up in the papers in which it is sold, and strongly heated in the stove until it becomes quite dry. In drying it splits up into the prismatic columns which are well known to the consumers of this domestic article.

Although so clean and beautiful an article is thus produced, the process of manufacture is really a very offensive one. The fermentation of the grains produces a foul acid water called *sour water*, and the putrefaction of the azotised substances of the grain produces a very offensive odour. "The sour water contains alcohol, acetate of ammonia, acetic and lactic acids, phosphate of lime, and gluten. The fermentation which takes place first is the vinous, at the expense of the sugar and a considerable portion of the starch; carbonic acid and alcohol are thus formed; the former is evolved as gas, and the latter remains in

the liquor. But when exposed to the air, and in presence of azotised matter in a state of decomposition, alcohol does not remain long without undergoing the acetous fermentation, and it is by the acetic acid thus formed that the complete separation of the starch and gluten is effected. The decomposition of a portion of the gluten gives rise to ammonia, which unites with some of the acetic acid to form acetate of ammonia. The lactic acid is a secondary product, arising from the fermentative decomposition of a portion of the starch. It probably assists the acetic acid in dissolving the gluten. The loss of a great portion of the starch and of all the gluten, and the insalubrity of the volatile products of the fermentation, render the improvements of this process highly desirable."[1] Some of these inconveniences have been overcome by falling back upon the old method of washing dough in water; for which purpose a trough is used with an upper false bottom perforated with numerous small holes; the dough, made with a very small quantity of water, is stirred up with a large pestle, while water is poured on from above. A wooden box below the trough receives the water containing the starch, and by continuing the operation long enough the whole of the starch is separated, and the gluten remains behind in the trough. The deposit of starch is, however, contaminated with gluten and other impurities; these are separated by fermentation, with one or two washings, and the starch is dried as before. This method is said to furnish about 55 per cent. of starch, and about 30 per cent. of gluten; whereas, the fermentative process previously described gives only 45 per cent. of starch and no gluten, and it is a great object to preserve the gluten, for this furnishes the chief material for making macaroni, vermicelli, &c. [See MACARONI.] Hence the French and Italians, who consume large quantities of these preparations, adopt that method of making starch that preserves the gluten.

Wheat is also used in the manufacture in an unground state, for which purpose it is sifted clean, and soaked in soft water until soft enough to be crushed between the fingers. It is then immersed for a short time in warm water, placed in bags, and exposed to strong pressure in a wooden chest containing water. The milky liquor thus obtained furnishes starch. In some starch works the swollen grain is ground between edge stones, [see Fig. 566,] and the crushed grain is repeatedly agitated with water in a large cistern, and thus the starch is separated.

The separation of starch from gluten by the action of an alkali, was introduced by Mr. Orlando Jones in 1840. This plan is well adapted to the manufacture of starch from rice. [See RICE.] The alkali used is caustic potash, or soda, and the solution must contain about 200 grains of real alkali to the gallon. If much stronger, the starch as well as the gluten would be dissolved. To 50 gallons of the solution 100 lbs. of rice are added, and left to macerate for 20 to 24 hours, a vessel of stone ware, of tinned iron, or tinned copper being used for the purpose. The alkaline solution of gluten is drawn off into a wooden vessel, by means of a tin syphon, or a tap, in the bottom of the vessel, the opening for which is covered with a finely perforated strainer. The rice left in the vessel is washed with plenty of cold water, which being drawn off, the rice is put in sieves to drain. It is then ground to flour, sifted, and again digested in the alkaline ley, 100 lbs. of flour to 100 gallons of ley. The deposit formed in the water used in washing the starch is added to this mixture. The flour is frequently agitated during 24 hours, and then left to deposit for 70 hours. The fibrous matter of the grain, with a little starch, is first deposited: and upon this a layer of starch. The solution, which is of a brownish yellow colour, and more or less turbid, contains all the gluten. The starch being deposited, the liquor is decanted, and the deposit stirred up with abundance of cold water. On being left tranquil for an hour, the fibrous matter with a little starch is first deposited, but most of the starch remains suspended. The liquor is now drawn off by a syphon, passed through a fine sieve to separate the husk, and is poured into a wooden cistern. The fibrous sediment is repeatedly washed until it ceases to yield starch. The liquor in the cistern is left to settle during about 70 hours; it is then decanted, and the starch is blued, drained, and dried as usual.

For inferior rice starches the deposit is not separated from the fibrous sediment by decantation, but the mixture is stirred up, passed through a fine silk sieve to separate the husk, and received into a wooden tank, where the final deposit is made.

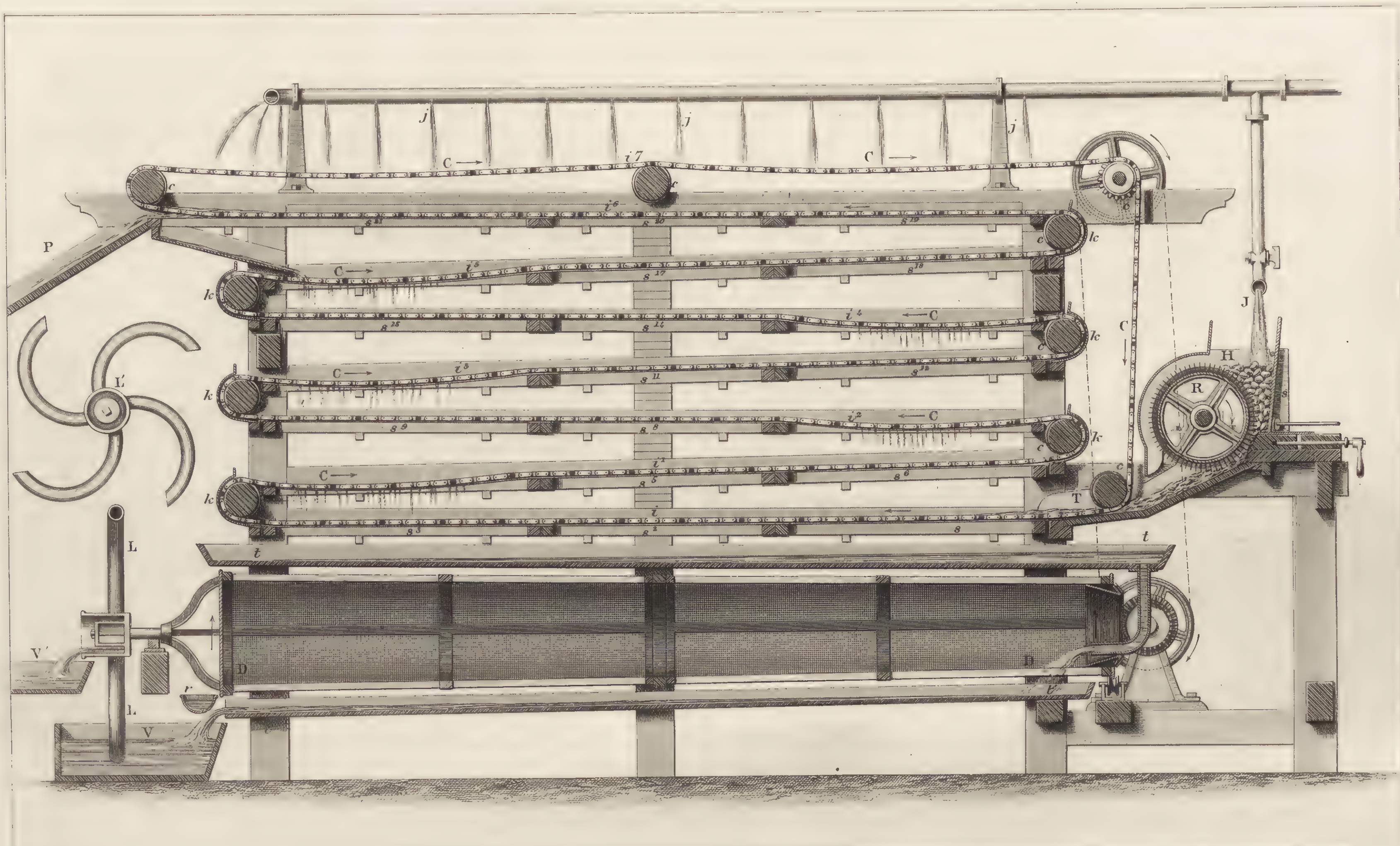
Starch is obtained from wheat by Mr. Jones's process, by mixing 50 lbs. of wheat meal with 100 gallons of the caustic alkaline solution, of the strength of 100 grains of real alkali to the gallon, agitating the mixture repeatedly during 12 hours, and leaving it for 70 hours to subside. The deposit consists of a layer of bran at the bottom, fibrous matter in the middle, and an upper layer of starch. The supernatant liquor is of a brownish yellow colour; it contains the gluten, and traces of other matters. The deposition being completed, the liquor is decanted, and the deposit stirred up with fresh water, and passed through sieves to separate the bran. The starch is separated from the fibrous matter, as in the case of rice starch.

One great advantage of Mr. Jones's process is, that the gluten can be recovered from the alkaline solution; for which purpose it is carefully neutralized with sulphuric acid. This precipitates the gluten, and when it has subsided, the clear supernatant liquor is decanted, and the precipitate washed, drained, dried in stoves, and ground into flour. In this state it is mixed with ordinary flour, used for making bread, biscuits, &c.

Carbonate of soda is sometimes preferred to caustic soda, on account of its greater cheapness, as a solvent for the gluten in the manufacture of rice starch. Muriatic acid has also been found useful for the same purpose.

The potato is largely used in making starch, espe-

(1) Parnell. Applied Chemistry, &c. Second Series. 1844.



STARCH. MACHINE FOR SEPARATING STARCH FROM POTATOES.

cially in France.[1] This valuable tuber has frequently been made the subject of chemical analysis: the following is an analysis by Michäelis of a red potato, richer in starch than the ordinary varieties, which usually contain from 5 to 8, or 9 per cent. of starchy fibrin, and from 9 to 15, or 18 per cent. of starch:—

Starch and starchy fibrin	30·469
Albumen	·503
Gluten	·055
Fat	·056
Gum	·020
Asparagin	·063
Extractive matter	·921
Citrates, silicates, and phosphates of potash, soda, lime, magnesia, alumina, and protoxides of iron and manganese	·815
Chloride of potassium	·176
Free citric acid	·047
Water	66·875
	100·000

The starchy fibrin, or amylaceous fibrin of the potato, differs from the fibrous matter of other plants: it consists mostly of a substance resembling common starch. Asparagin is a white, soluble, crystalline substance, found in the juice of the asparagus. The shoots of germinating potatos contain a small quantity of *solanine*, a very poisonous substance found in several species of *solanum*, such as *S. dulcamara*, or deadly nightshade. The tuber itself contains a small quantity, which is readily removed by the action of water. Cattle must not be fed on the residue of germinated potatos used in making starch, or their hind limbs will become paralysed from the action of the solanine.

The quantity of starch not only differs in the different varieties of potato, but also on the nature of the soil, the mode of culture, and the season of the year. Even the same kind of potato yields different proportions of starch at different seasons. M. Pfaff found that 240 lbs. of the same kind of potato yielded

	lbs.		lbs.
In August	23	to	25
,, September	32	—	38
,, October	32	—	40
From November to March	38	—	45
In April	38	—	28
,, May	28	—	20

Starch is not distributed equally over the tuber, but exists in largest quantity towards the exterior. In large potatoes the centre is often quite transparent, containing only cellular tissue and water. Just under the epidermis is also a thin layer of cellular tissue without starch: the tissue just beneath this contains the starch in large quantity, and the proportion gradually decreases towards the centre.

As the manufacturer of potato starch requires to keep a large quantity of potatoes in store, the best method of preserving them is a point of great importance. Potatoes may be kept for a year or more at the temperature of freezing water without loss of starch. It was formerly the practice to keep them in heaps in underground cellars; but the bruised tubers soon began to ferment, and the heat occasioned thereby led to a general fermentation and loss. Potatoes are now usually imbedded in large shallow ditches, called *silos*, dug in a sandy soil, if that be practicable. They are protected from the air by a thatch, and ventilating apertures are made by building trunks of wood in the mass.

In the manufacture of starch from potatoes, the first process is to soak the tubers in water for about 6 hours, which softens the epidermis, and assists in its removal. They are then passed through a hopper into a cylindrical cage, and washed by the revolution of the cage in a trough of water, while a jet of water falls on the cage. All the earthy matter and much of the skin are thus removed. The potatoes are now passed into a trough, and elevated by means of an endless chain with buckets attached to a rasping-machine, where they are passed under a circular rasp, a common form of which is a wooden drum covered on its circumference with sheet iron roughened outside by punching numerous holes from the inside. The rasp revolves from 900 to 1,000 times per minute, and a stream of water plays on its surface to prevent it from becoming clogged, and to wash off the pulp to which the potatoes are reduced by its action. The pulp is conducted into a cylindrical sieve of wire gauze, formed of 3 pieces of unequal diameters, and made to revolve by a winch. These cylinders are supplied with fresh water which, with the starch in suspension forming a milky liquid, falls into a trough, while the washed pulp is received in a separate vessel. A machine used in France in the preparation of potato-starch is represented in the steel engraving. The rasp R is a cylinder furnished on its circumference with toothed knives or saws separated from each other about $\frac{3}{4}$-inch, by means of iron plates: the knives are placed in the direction of the axis of the drum, and the teeth project from its surface about $\frac{1}{12}$th inch. The rasp rotates on its axis at the rate of about 800 times per minute. The rasp is contained in a hopper H, so contrived that, by hanging one of its sides *s* upon an axis near the top, and keeping the lower part of the same side pressed in towards the rasp, this side will yield at the lower part if by accident any hard body, such as a stone, should get into the hopper; but it opposes sufficient resistance when only the potatoes are between it and the rasp.

While the rasp is in action a stream of water J falls upon its surface, and thus assists the centrifugal force of the rasp in clearing its surface of the potato pulp. The pulp passes down a trough T, and thence to a series of wire-gauze sieves or strainers, mounted in fixed frames, one above the other. The pulp is passed over the first sieve s^1, and raised and distributed over the other sieves, s^2 to s^6, by means of scrapers attached to an endless articulated chain or band C C, which moves upon rollers *c c*. There are, of course, 2 of these endless chains, 1 on each side of the sieve frames, but in the engraving, which represents a vertical section, only one can be shown. The ends of the

(1) In M. Payen's "Précis de Chimie Industrielle," 8vo. Paris, 1851, is a valuable article on Starch, and its manufacture from the Potato, together with an experimental inquiry into the Potato Disease. In Dumas's "Chimie Appliquée," &c. tome vi., is an excellent chapter on Starch and its manufacture.

scrapers are let in to the articulated joints of the endless chains, and thus this moving system somewhat resembles a flexible or rope-ladder, the chains forming the sides and the scrapers the rounds. The rollers *c c*, round which the chains move, are boxed in with curved pieces *k k*, so that when the scrapers arrive with the pulp at the side extremity of any one of the sieves, they can turn round the rollers without losing any of the pulp, which is thus easily transferred from a lower to an upper sieve. Jets of water *j j* are constantly playing on the top sieve-frame s^6, and from this the water trickles through all the other frames, so that by the time the pulp has arrived at the top frame its starch is thoroughly washed out, and it is discharged down the spout P. The water charged with the fecula is received into a trough *t*, and passed by a bent tube into a cylindrical sieve D, of fine wire gauze, moving upon a horizontal axis. Here the remaining portion of the fibrous parts of the starch cells, which escaped separation by the sieve frames, are separated from the starch: this fine pulp is collected in a small receptacle *r*, while the starch water passes into a trough *t'* and thence into a vat V, where a danaide, water lifter or scoop L (shown in a separate figure L′), moving upon the axis of the drum D, raises the starch-water into a trough V′, which conducts it to the depositing vats.

The wire gauze of the frame s^1, s^2, &c. increases in fineness from the top: the gauze of the top frame s^6 is numbered 30, that of s^1 50, and that of the drum D 80. These numbers indicate the number of parallel wires in a width of 3 centimetres (1·19 inch). At each stage are plates of galvanised iron i^1, i^2, &c., curved so as to retain a portion of the water from the jets *j j*, and thus act as a momentary steep for the pulp in its passage across the sieve frames: this prevents the pulp from forming into knots, and assists the passage of the starch through the wire gauze.

The starch-water when received into the depositing vat quickly deposits its starch, and forms a coherent layer, from which the liquor is poured off. The potatoes, however carefully washed, always contain a little sand, which is now found in the first deposit of starch, and is separated by washings and decantations. On stirring up the starch with water the sand subsides almost immediately; and on running off the milky liquid into a separate vessel, a new deposit is formed free from sand. This deposit is covered with a light albuminous matter, which is removed by washing. The starch is then put upon cloths to drain, the cloths being contained in small trays with perforated bottoms, and when most of the water is thus got rid of, the trays are placed on a floor composed of pieces of well-dried plaster, which quickly absorbs the water, and leaves the starch as a firm, friable body, which is sent to market under the name of *green fecula*. It contains about 38 per cent. of water, and is used in the preparation of dextrine and starch syrup, &c. To obtain the starch in a dry state it is left for 24 hours on the plaster floor, then cut up into blocks, and broken into lumps, and placed on shelves in a drying-house. The pieces are turned over occasionally, and when they begin to crack the drying is completed at a hot stove, at a temperature of from 55° to 58° cent. (131° to 136° Fahr.), with occasional stirring, to prevent the formation of small hard lumps, and when dry it is bolted through a silken sieve. The substances left on the sieve are ground under a roller, and again sifted.

This kind of starch is hygrometric, and therefore not well adapted to the stiffening of linen: it generally contains about ⅕th its weight of moisture, but when saturated, about 23 per cent. It is often adulterated with gypsum, chalk, and argillaceous matters, which are easily detected by incineration. Potato starch is sold under various names for the purposes of food. It forms the basis of the "nutritive farina;" for which purpose the starch is carefully prepared, coloured and aromatized. "The Prince of Wales's food," "soluble starch," "Indian corn starch," "potato flour," "English arrowroot," &c. are all chiefly composed of potato starch. A variety of tapioca is made by heating moistened potato starch on a copper plate to nearly 212°: some of the granules of starch burst, agglomerate, and form small, hard and irregular grains, which resemble true tapioca. Starch of no kind can be used alone in making pastry; but a little potato starch or potato meal added to wheaten flour is thought to improve the quality of bread. [See BREAD.] If the proportion of potato starch exceed one-fifth the weight of the flour, a peculiar flavour is communicated to the bread, in consequence of the presence of a minute quantity of an oily matter contained in several amylaceous principles, and probably identical with the oil of potato spirit or fousel oil. [See DISTILLATION.] It is supposed to be a product of the fermentation of the potato, and not to preexist in the tuber: it has been obtained by fermenting and distilling the last syrup obtained in the manufacture of beet-root sugar.

Potato starch is also used in making grape or starch sugar [see SUGAR—BEER, &c.], and British gum or dextrine for the calico-printer. [See GUM.] It is also largely used as a substitute for glue in making size for paper, for which purpose it is mixed with a small quantity of a solution of resin with carbonate of soda in water.

The starch-water from which the potato starch is deposited is useful for the purposes of irrigation; it contains an azotised matter and small particles of pulp. The marc of the pulp is deprived of half its water by expression, and is then used as food for cows and sheep. If the quantity be too large for immediate consumption, it may be dried at a moderate heat, when it will keep for a year or more, and is fit for use on the addition of water. The practice of keeping it in heaps with salt is a bad one, as it is apt to ferment, and thus become valueless.

The methods of preparing arrowroot, sago, tapioca, salep, tous-les-mois, and Indian corn starch do not require any further notice after the above ample details, and what has already been said under ARROWROOT—SALEP, &c.

The duty on starch was formerly 3½*d.* per pound.

Before being put into the stove to be dried, each paper of starch was sealed or stamped by the Excise officer. The duty and the restrictions imposed by the Excise were very injurious to the manufacture; but on the recommendation of the Commissioners of Excise Inquiry the duty was abolished in 1833.

STATICS and DYNAMICS are two important divisions of the science of MECHANICS, the one determining the conditions of equilibrium of solids, and the other comprising the laws which determine their motions. The other two divisions, HYDROSTATICS and HYDRODYNAMICS, refer, the one to the conditions of equilibrium in fluids; whilst the other comprehends the laws of fluids in motion.

In its widest sense, Mechanics is the science of forces, whether those forces produce rest or motion. Forces that are balanced so as to produce rest, are termed *statical* forces or *pressures*, to distinguish them from *moving*, *deflecting*, *accelerating*, or *retarding* forces, or such as are producing motion, or a change in the direction or velocity of motion.

Statical forces or pressures are comparable only with each other: but the ratio between any two quantities may be represented by the ratio between two other quantities different in kind from the first. Thus, two pressures may have the same ratio as two lines, or two surfaces, or two bulks, or two times, or two numbers: and when numbers are used, some fixed standard is referred to as the unit of measurement, such as *inches*, *feet*, *miles*, &c., for the comparison of lengths; and *ounces*, *pounds*, &c. for the comparison of pressures.

Forces may also be represented by lines of definite lengths. A unit of length being taken to represent the unit of pressure, the length of the line represents the *magnitude* of the force; it may also represent its *direction*, which numbers cannot do: thus, while the direction of the line represents the *direction* of the force, the commencement or extremity of the line may represent its *point of application*, or the point at which the force acts. A force being represented by a line, a double force is represented by a line of double length, and so on.

When two forces are in equilibrium at a point they are equal in magnitude, and opposite in direction. If two equal forces act together in the same direction they produce a double force; three equal forces a triple force, and so on. Whatever number of forces act upon a point, and whatever their directions, they can only impart one single motion in a certain direction. Hence, all these forces may be incorporated into one force or *resultant*, which is capable of producing the same mechanical effect as the forces themselves, or the *components*, as they are called. If a new force equal to the resultant, and acting in a contrary direction thereto, be added to a system of forces, equilibrium will be maintained. If a number of forces act at a point in the same straight line, and in the same direction, the resultant is equal to their sum; but if the forces act in opposite directions, the resultant is equal to their difference. Equal and opposite forces may be added at any point without disturbing a system of statical forces, a process which is called the *superposition of equilibrium*. Equal and opposite forces may also be removed from any point in a system without disturbing equilibrium.

When two forces act on a point in different directions, the line representing the resultant is situated in the same plane which contains the directions of the two forces. When these forces are equal, the resultant evidently bisects the angle between their directions; but whether the forces be equal or not, the nearer they coincide in direction, the greater will be the resultant, and *vice versâ;* and as their exact coincidence makes the resultant equal to their sum, and their exact opposition makes it equal to their difference, so in all intermediate positions, the resultant will be less than their sum and greater than their difference.

If two forces be represented in magnitude and direction by the sides of a parallelogram, the resultant or equivalent force will be represented in magnitude and direction by its diagonal. For example, let the point P, Fig. 2019, be acted on by two forces pressing in the directions P A and P B; from the point P on the line P A measure off any length, such as P *a;* and from the point P, on the line P B, take a length P *b*, bearing the same ratio to P *a* that the force B bears to the force A. This may easily be done by making the lines P *a*, P *b*, contain respectively as many units of length, such as inches or feet, as the forces A B contain units of force, such as ounces and pounds. Through *a* draw a line parallel to P B, and through *b* draw a line parallel to P A, and let these lines meet at *c*. The parallelogram P *a c b* is thus obtained, of which the diagonal P *c* will represent a single force acting in the direction P C, and containing as many units of force as the line P *c* contains units of length, and this force will produce upon the point P the same effect as the two forces A and B produce acting together.

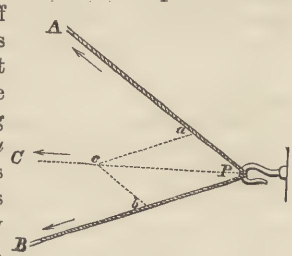


Fig. 2019.

By the same rule, any number of forces acting on a point can be compounded. If the body *x*, Fig. 2020, be acted on by 3 simultaneous forces, the directions of which are represented by the arrows A B C, and their magnitudes by the lengths *x a*, *x b*, *x c*, any two of them, such as A and B, may first be compounded by completing the parallelogram *x a d b;* the direction of their resultant is thus found to be *x d*, and its magnitude to their magnitudes as the length *x d* is to the lengths *x a*, *x b*. This resultant may next be compounded with the remaining force *x c*, by

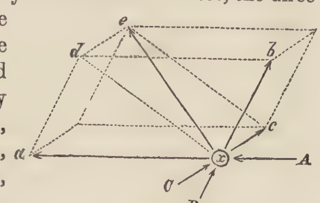


Fig. 2020.

completing the parallelogram *x d e c*, the diagonal of which, *x e*, represents the magnitude and direction of the resultant of all 3 forces; so that a force of the magnitude expressed by the length *x e*, and acting in the direction *e x*, would balance those 3 forces. The resultant of any greater number of pressures may similarly be found by combining two at a time. In the problem of the *parallelogram* of forces, Fig. 2019, the directions of the components and of the resultant lie in the same plane; but in the problem of the *parallelopiped* of forces, the directions of the forces may be in different planes. In such a case, the 3 lines *x a*, *x b*, *x c*, form the 3 edges, which meet at one solid angle of a parallelopiped, and by completing the solid figure, as shown by the outer dotted lines, its diagonal *e x* represents the resultant.

The solution of the problem of the *composition of forces*, may be greatly assisted by the inverse problem of the *resolution of forces*. It is often necessary to consider a force as capable of being resolved into 2 or 3 distinct forces having different directions, by substituting for any given force a number of other forces, with any given directions not opposite to each other. Thus, the line *x e*, Fig. 2020, may be made the diagonal of any number of parallelograms, or of parallelopipeds with their sides running in any proposed directions. When their directions are decided on, their lengths may be discovered; and thus we may ascertain both the directions and the magnitude of the forces into which the whole or resultant force has been resolved.

When a number of forces in equilibrium are acting on a point, each force is exactly equal and opposite to the resultant of all the rest. This property leads to the theorem of the *polygon of forces*, by which any number of statical forces are represented in direction and magnitude by the sides of a polygon taken in order; and they will, when applied to one point, produce equilibrium; or in other words, in order that the forces may form a polygon, they must be in equilibrium. For example, let P^1 P^2 P^3 P^4 P^5 Fig. 2021, be forces in equilibrium acting on a point A, and represented in magnitude and direction by the lines AP^1, AP^2, AP^3, AP^4, AP^5. To find the resultant of P^1 and P^2, complete the parallelogram AP^1CP^2, and the resultant will be AC. Compounding this resultant with the force P^3 by means of the parallelogram $ACDP^3$, AD represents their resultant, or the resultant of P^1, P^2, and P^3. Compounding this last resultant with the force P^4, by the parallelogram AP^4ED, their resultant is represented by the line AE, opposite in direction to the last force P^5, and equal to AP^5. This line completes the polygon AP^1CDEA, of which the sides AP^1, P^1C, CD, DE, EA represent severally in magnitude and direction the forces P^1, P^2, P^3, P^4, P^5.

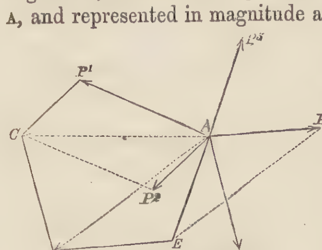


Fig. 2021.

Forces may be made to act side by side with as much effect as in the same straight line. The resultant of two *parallel forces*, as they are called, is equal to their sum; it has the same direction as the forces themselves, and when these are equal, it is applied at a point midway between their points of application. When they are unequal, the resultant, although still parallel with them, and equal to their sum, does not act midway between them. When they are equal, and act in contrary directions, they have no simple resultant, for they tend to produce rotation, and this tendency cannot be counterbalanced by any single force. The resultant of a number of parallel forces is obtained by a principle called the *equality of moments*. The point of application of this resultant depends solely on the points of application and the intensities of the components, and is not affected by any change in their directions, so long as they retain their parallelism and equality to each other. The forces with which the particles of a body at the surface of the earth tend to descend, or in other words, their *weights* or gravitating forces, are regarded as parallel to one another, since they all converge towards a point, viz. the earth's centre, the distance of which may be regarded as infinite compared with the size of the body. All these equal and parallel forces may be replaced by a single force applied to a certain point of a body, which point of application is termed the *centre of gravity*, or the centre of parallel and equal forces. It is a fixed point in the interior of solids, and does not change whatever position these bodies may be placed in with respect to gravity. (See CENTRE OF GRAVITY, where the methods of determining this point are briefly stated.) In order that a heavy and perfectly rigid body be in equilibrium, all that is necessary is, that its centre of gravity be supported. If the centre of gravity be fixed, the body may be turned about in all directions, and it will always rest in whatever positions it may be placed, because it will always be in equilibrium. When a body is supported at a fixed point, which is not its centre of gravity, equilibrium can be maintained only when the centre of gravity is in the vertical of the fixed point, either above or below.

A body placed on a horizontal surface, touching it only at one point, may assume various positions of equilibrium, some of which are *stable*, some *unstable*, and others *indifferent*. When a body is disturbed from its position of repose, and does not tend either to regain its former position or to increase the disturbance, but simply remains in the new position, it is said to be in *indifferent* equilibrium. If from the centre of gravity of a body, rays are produced to every part of its surface, the greater number of these rays will be oblique thereto; some will be perpendicular or *normal* thereto, whatever be the external form of the body. In general, there is a maximum ray and a minimum ray, both normal to the surface. There are also other rays, which are maximum or minimum among the surrounding rays, and which are

essentially normal. Now, if the body touch the horizontal plane by the extremity of one of these normal rays, the centre of gravity is in the vertical of the point of contact, and there is equilibrium; but if the body touch the plane at the extremity of an oblique ray, the centre of gravity is not sustained, since it is no longer in the vertical of the point of contact. In general, a body is in the position of stable equilibrium when the centre of gravity is as low as possible, because in a body free to move in any direction, the centre of gravity always assumes the lowest possible position. If the ray of the point of contact be normal, but not maximum nor minimum, but only equal to the neighbouring rays, the equilibrium is *indifferent*, as in the case of a sphere on a horizontal plane. If a portion of the upper part of the sphere be removed, as by drilling a hole towards the centre, the equilibrium becomes *stable*, because the centre of gravity is brought below the centre of the figure, and the ray from the centre of gravity to the point opposite the hole is a minimum ray. If the hole be filled up by inserting a plug, made so as to project beyond the surface, the centre of gravity is thrown nearer this projection than the opposite point, and a ray drawn to the latter will be a maximum ray, and the balance thereon will be *unstable*, because any motion sideways tends to lower the centre of gravity, and to enable it to fall still lower; whereas, when a body rests on a minimum ray, any rocking must raise the centre of gravity, so that it will tend to fall back to its previous position.

It has been stated that the resultant of two parallel and equal forces, is a parallel line situated midway between them, and that when the forces are unequal, the resultant is so situated that its distance from them is inversely as their intensities. Hence it follows, that when two parallel but unequal forces are supported or balanced by a third or resultant force, this third force must be equal to the sum of the other two: it must act in a contrary direction, and be applied at a point nearer the greater force than the less, its distances from them being inversely as their intensities. When, therefore, a force applied to any point of an inflexible bar, supports two other forces applied in the contrary direction to two other points of the bar, the above condition must apply. For example, when the 3 forces, B, A, and *a*, Fig. 2022, are in equilibrium, B is to A as the distance A *a* is to the distance B *a*. Such a case as this may represent the steelyard. [See BALANCE, Figs. 89, 90.]

When one point of a rigid body is fixed, the effect of any forces applied to that body is to turn it round the fixed point as a centre of motion. When 2 points are fixed, the motion can only be round the line or *axis* which joins them. In such cases, 2 forces which tend to turn the body in contrary directions are in equilibrium if their intensities are inversely as their distances from the centre or axis. But, as in every proportion the product of the extreme terms is equal to that of the means, we may, instead of saying that the forces A and B, Fig. 2022, are inversely as the distances *a* A and *a* B, adopt the simpler, but equivalent expression, that the product of the force A × the distance *a* A = the product of the force B, × the distance *a* B. If both forces be measured by the same unit of pressure, and both distances be measured by the same unit of length, the number that represents each force being multiplied by the number that expresses its distance from the axis, the product will be the same in each case. Thus, if a straight bar, Fig. 2022, be balanced, and at the distance of 1 foot from its *fulcrum* or point of support, a weight of 12 lbs be suspended, it will be found that this weight will be balanced by a weight of 6 lbs. at the distance of 2 feet on the other side of the fulcrum; or by 4 lbs. at the distance of 3 feet; or by 3 lbs. at the distance of 4 feet. By multiplying these weights by the number of units (feet) which represent the distances from the centre, we get 12 in each case. These products are called the *moments* of the force, and it is evident that any 2 forces applied to a body supported on an axis, and tending to turn it round, will be in equilibrium when the moments of the 2 forces are the same. The moment may also be increased or decreased in any proportion, and the efficacy of the force in turning the body round the axle will be increased or diminished in exactly the same proportion. So, also, by increasing the number of forces on each side of the axis, the body will be in equilibrium, provided the sum of the moments on one side of the axis equals the sum of the moments on the other side of the axis.

This principle of the *equality of moments* is the most important in the whole range of mechanical science. It may be further illustrated by the *principle of virtual velocities*, or that which regulates the action and constitutes the efficacy of every machine in which power is employed to overcome weight or resistance. If, for example, 2 weights in equilibrium, as in Fig. 2022, at the extremities A and B of a bar supported on an axis *a*, passing through the centre of gravity, be made

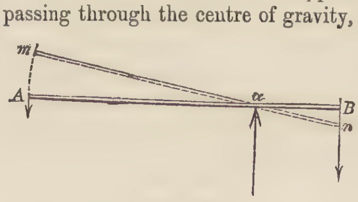


Fig. 2022.

to oscillate gently through a small space, it is evident that the spaces moved through by the 2 ends of the bar will be directly as their distances from the axis; for, the angles A *a m* and B *a n* being equal, the arcs A *m* and B *n* are as their radii *a* A and *a* B. For instance, if the weight B be 12 lbs., suspended at 3 inches from *a*, its moment may be expressed by the number 36; and it will be balanced by a weight of 6 lbs., 6 inches from *a*, because its moment is also 36. Now if these 2 weights be made to oscillate through a small space, such as B *n*, for the weight which descends, and A *m*, for the weight which ascends, the latter space will be only half the former, because it bears the same ratio to *a* B (or 3 inches) that A *m* bears to *a* A (or 6 inches). Hence, if B *n* be 1 inch, A *m* will be 2 inches, and the products of these 2 quan-

tities, with their respective weights, will be equal to each other; that is, the effect of 12 lbs. moving through 1 inch, or of 6 lbs. moving through 2 inches of space, is the same. And although we omit the consideration of motions, and deal only with *pressures*, the same principle applies to them. Any 2 pressures, however unequal (a pressure of 1 lb. and one of 1,000 lbs., for instance), will balance each other, if they are so applied that the motion of the first through 1,000 inches would be necessarily accompanied by a motion of the second through *one* inch, and *vice versâ*. Any means by which this connexion between the 2 pressures is effected, is called a *machine*.

In the composition of machines there are 6 so-called *mechanical powers*, or more properly *mechanical elements* or *simple machines*, by the combination of which all other machines are formed. The mechanical powers are the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge* and the *screw*. These contrivances are properly only applications of the principle of virtual velocities, whereby a small force acting through a large space is converted into a great force acting through a small space. And in these arrangements power is neither gained nor lost, the whole advantage consisting in the mode of application. Every pressure acting with a certain velocity, or through a certain space, is capable of being converted into a greater pressure, acting with a less velocity, or through a smaller space: the quantity of mechanical force is not altered by the change, and all that the mechanical powers can accomplish is to effect this change.

The *first mechanical power*, the lever, is a bar or rod, which, for the purpose of simplifying the study of its more essential properties, is supposed to be perfectly rigid and without weight. It may be *straight* or *bent*, *simple* or *compound*. There are 3 kinds or varieties of the straight or simple lever, each kind depending on the position of the point of application of the *moving power*, and the *resisting power*, with respect to a certain fixed point called the *fulcrum*, about which the lever is supposed to turn freely. The portions of the lever situated on each side of the fulcrum are called the *arms* of the lever.

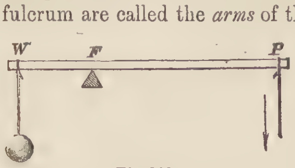


Fig. 2023.

In a lever of the *first kind*, Fig. 2023, the fulcrum F is situated between the moving power P and the resistance or load W. Levers of this kind are in very common use; such as a crowbar used for raising stones, and a poker used for raising the coals in the grate, the bar of the grate being the fulcrum.

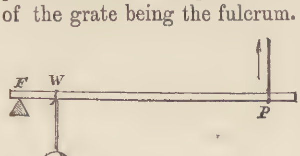


Fig. 2024.

In a lever of the *second kind*, Fig. 2024, the power P and the resistance W, act on the same side of the fulcrum; the load *W* being between the fulcrum and the force which moves it. A familiar example of a lever of this kind is shown under PARING-KNIFE, Fig. 1591, the hook at the end being the fulcrum; the wood to be cut is placed under it, and is the load or resistance to be moved or overcome; and the power is the hand of the workman at the extremity of the blade. A wheel-barrow is also a lever of the second kind, the wheel being the fulcrum, the contents of the barrow, the weight, and the man wheeling it, the power.

In a lever of the *third kind*, Fig. 2025, the power and the load also act on the same side of the fulcrum, but the power P is between the fulcrum F and the load W. A fishing-rod may be taken as an example of a lever of the third kind. The limbs of animals also furnish instructive illustrations of this kind of lever.

Fig. 2025.

It is evident from the foregoing statements, that in all these levers the power P will sustain the weight W, if the moment of P equal that of the weight. Thus in a lever of the first or second kind, if W be 12 lbs. at the distance of 3 inches from F, its moment will be 36, and it will be balanced by 6 lbs. at P, if P be at the distance of 6 inches from F, or by P = 4 lbs at the distance of 9 inches from F, and so on.

An example of a curved or bent lever is given under BALANCE, Fig. 91. For an example of the *composition of levers*, see WEIGHING-MACHINE.

The *mechanical efficacy* or *power* of a machine is said to be greater or less, according as the ratio of the weight to the power is greater or less. If the weight be 20 times the power, the mechanical efficacy is said to be 20: if 4 times the weight be equal to 25 times the power, the mechanical efficacy is $\frac{25}{4}$ or $6\frac{1}{4}$. Now, as the mechanical efficacy of the lever may be varied by varying the distances from the fulcrum of the power and the weight, a lever may be imagined equal to that of any given machine; such a lever with respect to that machine is called an *equivalent lever*. All simple machines may be represented by simple equivalent levers, and the most complex machine may be represented by a compound system of equivalent levers, of which the alternate arms, beginning from the power, bear the same proportion to the remaining arms.

The chief use of the common lever is to raise weights through small spaces, which is accomplished by a series of short intermitting efforts, the weight being supported in its new position while the lever is readjusted for a fresh effort. This want of range, and the means of supplying continuous motion, are defects in the common lever, which are, to a certain extent, remedied in the *rack and pinion*, shown in the SCREW-JACK, Fig. 1942; but in such a case the range is limited by the number of teeth in the rack. By filling up the spaces between the leaves of the pinion, it is converted into a *cylinder* or *barrel*, on which a rope may be coiled, and the load be suspended from it. In such a case, the rope will supply the place of the

rack A B, Fig. 1942, and be wound up in the same manner. This forms the common *windlass*, in which the weight hanging on the rope exceeds the force applied to the winch, and just supporting it, in the ratio that the length of the winch, measured from its centre of motion, exceeds the mean radius of a coil of rope, *i.e.* the radius of the barrel + half the thickness of the rope. Hence the efficiency of the windlass as a concentrator of force is increased by diminishing the thickness of the barrel, or otherwise by increasing the length of the winch; but the barrel would be too weak if diminished beyond a certain extent, and the winch would be useless if lengthened beyond the radius of the circle, which the hand and arm can conveniently describe. Hence the necessity for multiplying the winch or the *long* arm of the lever, and making it into several radii, just as the *short* arm was multiplied to form the pinion or barrel. This repetition of the longer arm constitutes the *wheel*, which, although reckoned as the *second mechanical power*, is in fact only a modification of the first. The advantage of the wheel over the single spoke or winch is, that however long its radius, it can always be turned continuously round by a force whose action is confined to a small part only of the circumference. This can be effected either by forming projections on the rim of the wheel, to be successively acted on by the power, in the same way that the leaves of the pinion successively act on the resistance; or secondly, by passing a rope or band round the wheel. The consideration of the former method must be referred to WHEEL-WORK; but we may here remark, that the second method readily exhibits the properties of this most important machine. The power is represented by a small weight suspended from a cord, wound on the circumference of the wheel; and the resistance by a larger weight, on a cord wound in a contrary direction round the axle. The condition of equilibrium is in this case the same as in the lever, only the power is multiplied by the radius of the wheel, and this is equal to the resistance multiplied by the radius of the axle. If the power be 1 pound, and the radius of the wheel 22 inches, the load 11 pounds, and the radius of the axle 2 inches, there will be equilibrium, because the moments are in each case the same. So also on the principle of virtual velocities, in one revolution of the wheel the power descends through a space equal to the circumference of the wheel, and the weight is raised through a space equal to the circumference of the axle. Hence the moving power, multiplied by the velocity of its motion, is equal to the load moved multiplied by the velocity of its motion. The axle of the wheel is not intermittent in its action, as in the common lever; but the motion which the power communicates to the load, although slow, is constant. Hence it is sometimes named the *continual* or *perpetual lever*, and its mechanical efficacy depends on the ratio of the radius of the wheel to the radius of the axle, or the length of the lever by which the power acts, to the length of that by which the load resists.

There are various methods of applying the power to the wheel, such as by pins placed round its circumference, as in the wheel used to work the rudder of a ship, in which case the hand is the power. Sometimes the rim of the wheel is dispensed with, and a number of long bars are inserted in the axle, as in the larger kinds of windlass, where the axle is usually horizontal. In the capstan it is vertical. [See CAPSTAN.] In either case the wheel consists only of diverging spokes, rendered portable by holes in the axle, for the insertion of spokes or *hand-spikes*, which are worked by men. When the axis is horizontal, each handspike is removed from one hole to another, the weight being meanwhile sustained by a *ratchet-wheel.*

With a vertical axis a number of men may push the bars before them, without any intermission of power, and thus an enormous weight may be raised. Several applications of the *ratchet*, or *racket-wheel*, are pointed out under HOROLOGY; but we may again refer to this simple but effective contrivance for preventing the turning of a wheel, except in one direction. A catch plays into the teeth of the wheel A B, Fig. 2026, permitting it to revolve in the direction of the arrow, but preventing any recoil on the part of the weight or resistance contrary to the direction of the power.

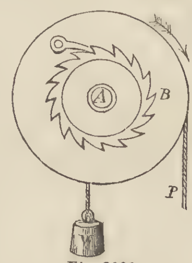


Fig. 2026.

Levers owe much of their mechanical advantage to their inflexibility; whereas ropes and cords are valuable for a contrary property. A rope is a machine which allows force to be transmitted from one point to another in the direction of its length, but on this condition that the opposing forces are *divellent;* whereas, in a rod or lever they may act from or towards each other. By means of the flexibility of the rope, a force acting in one direction may be made to balance an equal force in any other direction. Thus the weight W, Fig. 2027, acting in the direction R W, may, by means of a rope, passing through a fixed ring R, be sustained by a power P, acting in the direction P R. The alteration in the direction of the power, by passing the rope through the ring at R, makes no difference in the power, but merely allows of a change in its direction. This supposes the rope to be perfectly smooth and flexible, and the ring to be free from all roughness: but as it is not possible to fulfil these conditions, the friction arising from the opposite qualities is greatly diminished, by substituting for the ring a wheel grooved at the circumference, and turning freely on an axle, passing through its centre. Such a wheel is called a *pulley.* [See BLOCK.] By a proper arrangement of pulleys, force may not only be transmitted, but *concentrated.* Thus the pulley is called the *third mechanical power*, but no mechanical advantage is gained from the *pulley* as such, the cord

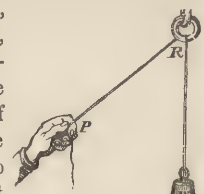


Fig. 2027.

or rope being the efficient agent; the real mechanical advantage is founded on the fact, that the cord must undergo the same tension in every part of its length. Pulleys are *fixed* or *movable*, according as their blocks or frames are fixed or not. In Fig. 2027 the power and the load are equal, whether the rope pass over a fixed pulley or a fixed ring. In such a case, as already observed, there is no mechanical advantage, but only a convenience in being able to apply the power in any required direction. In Fig. 2028, the weight W is equal to 4 times the power P. Now, the rope must have the same tension everywhere throughout its length, or the system would not be in equilibrium, and in order to be in equilibrium the tension must be equal to the power; the power P is supported by the tension of that part of the rope situated between C and P, and as the tension is everywhere equal, it follows that the 4 portions of the rope which connect the 2 pulleys, are each adequate to the support of the power, and calling this 1 lb. then W will be 4 lbs. In systems of pulleys with one rope and one movable block, the load is as many times the power as there are different parts of the rope engaged in supporting the movable block; and in general when the power acts downwards, the number of pulleys required is equal to the number of times that the power is to be concentrated; but when the power acts upwards, one pulley may be dispensed with, since, in Fig. 2028, the power P may be applied to pull up the cord *a*, without the intervention of the fixed pulley C, which adds nothing to the mechanical effect.

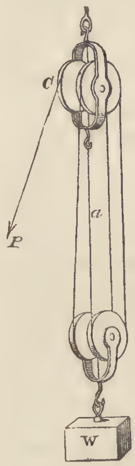


Fig. 2028.

In applying the dynamic principle of virtual velocities to the pulley, it will be found that whatever is gained in force is lost in velocity: the ascent of the weight is as many times less than the descent of the power, as the weight itself is greater than the power. Thus, in Fig. 2028, if the power be 1 lb. and the weight 4 lbs., and it be required to raise the weight 1 foot, the power must descend through 4 feet; for, in order to raise the movable block 1 foot, each of the 4 portions of cord by which it hangs must be shortened 1 foot; but as they all form parts of one continued cord, this must altogether be shortened 4 feet, or in other words, 4 feet of cord must pass out from the system between the blocks. Thus, no power is gained by the pulley: its sole advantage is to enable us to economize power, and expend it gradually. In raising a weight of 50 lbs. 1 foot high, the expenditure of power is obviously the same, whether we accomplish the task by raising 1 lb. through 50 feet, or 50 separate pounds through 1 foot; and in the pulley or any other machine, a weight of 50 lbs. cannot be raised to a given height with a less expenditure of power than is required to raise 100 lbs. half that height, or 1 lb. 50 times that height.

The *fourth* so-called *mechanical power* is the *inclined plane:* it is regarded in mechanical science as a perfectly hard, smooth, inflexible surface, inclined obliquely to the weight or resistance. The line A C, Fig. 2029, is called the *length* of the inclined plane B C its *height*, and A B its base. A heavy body G placed upon it will act in the vertical direction G V of a line passing through its centre of gravity G. This line G V may be made the diagonal of a parallelogram G W V X, so that if G V represent the magnitude and direction of the weight, it may be resolved into the two forces represented in direction and magnitude by G W and G X, one of which is parallel, and the other perpendicular to the plane: hence the pressure G V is equivalent to two other pressures, G W and G X, the former of which, G W, is destroyed by the resistance of the plane; and the latter, G X, only acts so as to cause the descent of the body down the plane. Now G X is to V G as B C is to A B; that is to say, a weight placed upon an inclined plane is propelled down the plane by a force bearing such proportion to the weight as the height of any section of the plane bears to its length. If, therefore, it were required to draw the heavy body G up the plane, any pressure in the direction X G exceeding G X, and the friction, would be sufficient to do so; and any pressure in the same direction which with the friction equals G X, would hold the weight in equilibrium.

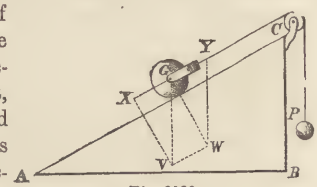


Fig. 2029.

Now to test this case of the inclined plane by the principle of virtual velocities, let the weight G be at the foot of the plane, and the power P at the top; then let P descend in the direction C B, until G arrive at the top of the plane. P will have descended through a depth equal to the length of the plane, while G will have ascended through a depth equal to its height; hence the perpendicular spaces through which the weight and the power move in the same time are in the proportion of their velocities. The proportion of the weight to the power is that of the length to the height: hence the power and the weight are reciprocally as their virtual velocities. $P \times$ the space through which it moves $= W \times$ the space through which it moves. Hence, if the height of the plane be 2 feet, and its length 50 feet, P will descend 50 feet, while W is raised 2 feet in vertical height; and accordingly P must be $\frac{1}{25}$th of the weight of W, in order to effect this; or rather greater than this, on account of friction.

When the inclined plane is movable, it is termed the *wedge*, and has been called the *fifth mechanical power.* In its simplest form, as used for raising weights, by thrusting an inclined plane under the load, instead of lifting a load by moving it along an inclined plane, the theory is this:—the moving power must bear to the resistance moved the ratio which the height of the plane bears to its *base*, and not as in the fixed plane, Fig. 2029, the ratio of the height to the *length.* In the fixed plane, therefore, the power

always balances a load greater than itself, however steep the slope may be; but in the wedge the power and the load will be equal, if the slope be 45°; and if steeper than this, the power must be greater than the load. The wedge, however, is commonly used for separating two surfaces that are pressed together by some force which constitutes the resistance; and in such case it must be regarded as a *double* wedge, or two inclined planes joined base to base. Such a wedge is commonly used for cleaving timber, in which case the power acts by percussion. But when regarded as a simple machine, the same rule is applied to it as to other simple machines, the force acting on the wedge being considered to move through its length *d* C, Fig. 2030, while the resistance yields to the extent of its breadth A B. The force of percussion differs so entirely from continued forces, that it admits of no numerical comparison with them; that is, it is not possible to define the proportion between a blow and a pressure. Hence the theory of the wedge is of very little practical value; and indeed its most valuable property, the *friction* between its surfaces and the substance which they divide, as in the case of nails used for binding substances together, is omitted in theory.

Fig. 2030.

The *sixth mechanical power*, the *screw*, is another variety of the movable inclined plane. We have seen, under SCREW, that the thread may be formed by wrapping an inclined plane round the surface of a cylinder; and in its application as a simple machine the power is usually transmitted by causing the screw to move through an internal screw or *nut* N, Fig. 2031, and the power may be applied either to turn the nut while the screw is prevented from moving, or to turn the screw while the nut remains fixed. Neither effect takes place without producing a longitudinal motion of one or the other, whichever meets with least longitudinal resistance; but this resistance may exceed the turning power in the proportion that the revolving motion exceeds the longitudinal motion. Thus power is gained at the expense of motion, as in all other cases where power appears to be increased. But in the application of the screw, shown in Fig. 2031, a compound machine, consisting of the lever and the screw, is produced. The power is applied to the end of the lever at P, while the weight or pressure W is sustained by the screw, as in the common screw-press. Supposing the distance, A B, between any two threads of the screw to be half an inch, and the circumference of the circle described by turning round the end of the lever P to be 5 feet, or 120 half-inches, then a force or pressure of 1 lb. at P would sustain 120 lbs. at W. In such an example all consideration of friction is omitted; and this, in the case of the screw, is very great, and is generally sufficient by itself, as in the wedge, to balance the longitudinal force, without any assistance at P. Indeed, it is seldom that any amount of longitudinal force is sufficient to turn the screw, for the threads would be destroyed rather than turn. The condition of equilibrium in the screw is, that the power, multiplied by the circumference which it describes, is equal to the weight or resistance, multiplied by the distance through which the screw or nut can move longitudinally during one turn; that is, the distance between the centres, or other corresponding parts of two contiguous threads, or rather turns of the same thread, which distance (which is twice A B, Fig. 2031, in double-threaded screws) is called the *pitch* of the screw; or the power : the weight : : the pitch : the circumference described by the power; which agrees with the principle of virtual velocities.

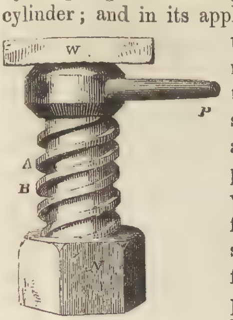


Fig. 2031.

The mechanical efficacy of the screw may be increased, either by causing the power to move through a greater space by increasing the length of the lever, or secondly, by increasing the number of turns of the thread. For if, in the above example, the pitch were $\frac{1}{4}$ instead of $\frac{1}{2}$ an inch, the other conditions remaining the same, the efficacy of the machine would be doubled, and the power of 1 lb. would sustain 240 lbs. instead of 120 lbs.

Such is a very brief notice of the mechanical powers. For a more extended notice of them and their applications, we must refer to other works, such as those mentioned below,[1] the first of which will also introduce the student to the study of dynamics, which can scarcely be entered upon in this place; nor, indeed, will such details be expected of us, in a work devoted to the useful arts and manufactures, rather than to the principles of science. But knowing how greatly the success in practice, and the appreciation in study, of manufacturing processes depend on the thorough knowledge and skilful application of scientific principles, we have been induced to insert a few short articles on those principles, in order that the reader may be induced to study them more fully in other works, and adopt them as a basis in working his own peculiar pursuit, or in studying manufacturing details.

In the science of statics, force is regarded simply as that which is necessary to oppose or balance force. In dynamics, force is regarded as the cause of *change of motion*. Mechanical forces are considered as motions actually produced, or tending to be produced, without any reference to the nature of

(1) For a more extended notice of the mechanical powers, and for the subject of statics and dynamics, the Editor begs to refer to "Rudimentary Mechanics." In conjunction with this work, he would recommend the study of Mr. Baker's "Principles and Practice of Statics and Dynamics," with examples wrought out by common arithmetic; and also "Elements of Mechanism," by the same writer. In this work are elucidated the scientific principles of the practical construction of machines; while in Mr Law's "Rudiments of Civil Engineering," with a continuation by Mr. Burnell, the most important applications of statics to the equilibrium of fixed structures are treated of. All the above-named works are in Mr. Weale's cheap and useful Rudimentary Series.

the force, or its generating cause. Hence two forces, which impart to the same body the same degree of speed in the same direction, are regarded as identical, whether they originate from animal power, a weight descending by its gravity, the impact of a heavy body, or the elasticity of steam, &c. Force is not required for the maintenance of motion, but only for its change, that is, for producing, *first*, a change of *state* from rest to motion, or from motion to rest; *secondly*, a change in the *velocity* of motion either by accelerating or retarding it; or *thirdly*, a change in its *direction*, by deflecting it upwards, downwards, to the right or to the left. And since matter is *inert*, that is, has no tendency either to rest or motion, a body impressed with that motion must persist in that motion, in a straight line, and with uniform velocity, for ever, unless some new force, (such as friction, resistance of the air, &c.) act upon it, either to change its state, its direction, or its velocity; for it cannot of itself change either its state of rest or its state of motion, its velocity or its direction.

We may thus regard as being in equilibrium, not only such bodies as are at rest, but such also as are performing uniform rectilinear motion; for it is only while their velocity or direction is changing, that is, while they are being *accelerated*, *retarded*, or are moving in a *curve*, that the forces acting on them can be unbalanced, or can produce a resultant pressure; and as long as this pressure remains unbalanced, the motion will continue changing in velocity, or direction, or both; whenever it becomes straight and uniform, the resultant of all the forces acting on the body = 0, or it is not subject to any unbalanced force. The dynamical effect of force being then a change in motion, a continued force must produce a continuous change, whether in velocity or direction. The simpler effect of a sudden change of velocity, or an angular deflection, can only be produced by an instantaneous exertion of force, or an *impact*, as it is called. The force of any moving body, or its *momentum*, or *quantity of motion*, is the product of its mass by its velocity. Now it is established, 1. that when equal masses are in motion, their forces are proportional to their velocities; 2. that when the velocities are equal, the forces are proportional to the masses or quantities of matter; 3. that when neither the masses nor the velocities are equal, the forces are in the proportion of both taken jointly, that is, the proportion of their products.

These theorems may be illustrated by two balls of clay, A B, Fig. 2032, or of some other comparatively non-elastic substance, suspended from C by strings, so as to hang in contact in the middle of a graduated arc D E. The arc should be cycloid, and divided not into equal parts, but as shown in the figure, so that the numbers 1, 2, 3, &c. may be proportional to the perpendicular heights above the level of the point 0. Now it has been proved in the case of gravity, 1st, that when a ball thus suspended is let fall from any point of the arc, its velocity will be the same whatever be its mass; 2d, that this velocity will continually increase until it reaches the point 0; 3d, that on arriving there, its velocity is proportional to the square root of the vertical height which it has descended; 4th, that if it start from 0 with this same

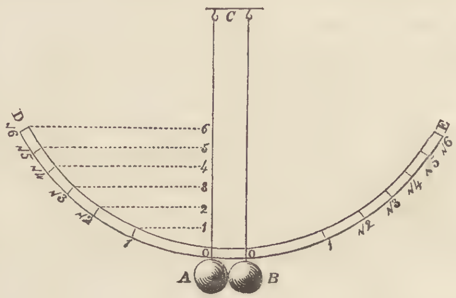


Fig. 2032.

velocity, it will ascend to the same height from which it must have fallen to have acquired that velocity and no higher, because its velocity is by the action of gravity constantly diminished, until at this precise height it is destroyed. The velocities of the balls, therefore, at the moment of their arrival at, or departing from the point 0, may be exactly measured by noting the divisions on the scale from which they have descended, or to which they ascend, provided the 4th division be reckoned 2, the 9th division 3, and so on. Now, suppose these balls to be equal in mass, and to be moved in opposite directions, A towards D, and B towards E, and then allowed to fall at the same moment; if the balls fall through equal arcs, they will of course impinge upon each other with equal velocities, and each will destroy the force of the other and remain at rest, for *equal masses* having *equal velocities*, must have *equal forces*. If, however, the ball A be double the weight or mass of B, and A be raised towards D, as far as the first division, and B towards E as far as the fourth division; when allowed to descend at such an interval of time as to bring them both at once to the point 0, their velocities will be as $\sqrt{1} : \sqrt{4}$, or as $1 : 2$; but as their masses are as 2 to 1, their forces will be as 2×1 to 1×2, or equal. Accordingly, after impact, these two bodies will remain at rest, because the equal and opposite forces have destroyed each other. So also if the masses of the balls be inversely as their velocities, their forces will be equal, and they will remain at rest after impact. If we now suppose A and B, Fig. 2032, to be unequal in mass, but equal in velocity; that A is twice the size of B, and that each is allowed to descend from the same height at D and E; if the velocity of each be called 6, the quantity of motion in A may be expressed by $2 \times 6 = 12$, while that in B will be $1 \times 6 = 6$. After impact the 6 parts of motion in B will destroy 6 parts of the 12 in A, leaving only 6 parts in both bodies. Now, the combined mass of both being = 3, and their momentum = 6, their velocity must be 6 divided by 3, or = 2; so that both will move on together with a velocity of 2, that is, $\frac{1}{3}$d of their velocity before impact, and this will carry them $\frac{1}{9}$th the height from which they descended. Similar results will be obtained when the

balls are equal in mass, but have been raised to different divisions.

If, instead of clay-balls, balls of ivory, or some other elastic material, be used, the quantities of motion which oppose each other are not *destroyed*, as with non-elastic bodies, but *reversed*. If the balls be equal, on removing A from the vertical up to any division, such as $\sqrt{4}$, on the arc, and allowing it to descend and impinge on B, which is at rest, B receives the whole of A's motion, leaving A at rest, and starts off with the force of A ascending the same number of degrees on the opposite scale that A had descended. If a number of ivory balls of the same size be suspended, as in Fig. 2033, and the first be removed from the vertical and allowed to impinge on the others, the last only, No. 7, is moved, and this starts off with the quantity of motion which No. 1 had the moment it struck No. 2. If 1 and 2 be both raised from the vertical, and allowed to fall together, the last two, 6 and 7, will be raised.

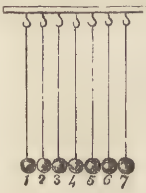


Fig. 2033.

When bodies move in the same direction, the phenomena of impact may also be obtained if such bodies move with different velocities. Thus, if a non-elastic body be overtaken by another, the two bodies after impact will move with a common velocity. If they be equal in mass, half the sum of their velocities will be their common velocity after impact. If, before impact, A move with the velocity of 5 and B with that of 3, the common velocity of the two bodies after impact will be 4, or half the sum of $5 + 3$. If A and B be unequal in mass, A being 9 and its velocity 12, its quantity of motion will be 108. If the mass of B be 7, and its velocity 9, its quantity of motion will be 63. The sum of the two motions will be $108 + 63 = 171$, and this will be the whole motion of the united masses after impact. Divide this by the united masses, $9+7=16$, we find that $171 \div 16 = 10\frac{11}{16}$ths, the common velocity of the united masses. When a moving body comes in contact with a body at rest it can only continue its motion by pushing this body before it, and imparting to it such a quantity of motion, that after impact they move with a common velocity. If the two bodies be equal, the motion after impact will be equally divided between the 2 masses, and the velocity will be only 1-half, since the mass has been doubled. If the mass at rest be double that of the moving body, the velocity, after impact, will be only 1-third of that of the moving body; and in general, when a moving body communicates motion to a body at rest, the united velocity of the 2 bodies is, to that of the moving body, as the mass of the latter is to the sum of the masses of both.

The law of *uniformly accelerated motion* in the case of falling bodies, is briefly stated in our description of the *cam*, under ENVELOPE-FOLDING-MACHINE. The pendulum is noticed under HOROLOGY. The laws of *uniformly retarded motion*, *composition of motions*, *projectiles*, *centrifugal force*, &c., are treated of in "Rudimentary Mechanics," already quoted.

STAVES. See COOPERAGE—LEVELLING.

STEAM, or AQUEOUS VAPOUR, is the same substance which in its liquid state we call WATER, expanded into an aeriform state by the addition of heat. Steam is not necessarily hotter than water, but nevertheless always contains more heat, as will presently appear. A large portion of the heat (or rather of the cause of heat) in all bodies, has no effect in rendering them hotter, and is therefore called *latent heat*, and of this there is always more in a liquid than in the same substance when solid, and much more in it when aeriform or vaporous than when liquid. But as the remaining heat not latent (called the *sensible* or *apparent* heat) may be equal in all three states of the body, all may be equally hot or of the same temperature. Thus, at all temperatures between 5° or 10° Fahr. and 32°, water, ice, and steam have been known to exist together, all with the very same temperature; and although ice may seem to be incapable of being raised to a higher temperature than 32°, yet at all higher temperatures to which aqueous matter has been exposed, it can exist at once both as water and as steam, differing not in their temperature or amount of sensible heat, but only in that of their latent heat.

Water being the most abundant surface matter of our planet, its vapour, steam, is the most abundant of vapours properly so called, (that is, of aeriform bodies capable also of existing as liquids at the same temperature,) and indeed, with two exceptions, is the most abundant of all the airs or gases; for it constitutes about 1-hundredth of the weight of the entire atmosphere, and is its third ingredient in quantity, the most abundant, namely the nitrogen, being 77-hundredths, and the second, the oxygen, 22-hundredths. The proportion of steam, however, is always varying at any particular spot (for reasons which will presently be explained), and always exceeds this average in warm countries, and falls short of it in cold ones. Air without steam, however (theoretically called *dry* air), is not known to exist in nature, and is probably not producible by art.

Steam has the mechanical and optical properties of common air, that is to say, it always fills any artificial space that may be allowed it, however large, and always presses against the whole of the enclosing surfaces, equally in every direction, and with a pressure which (other things being equal) diminishes in the same ratio that the space is enlarged, and increases in the same ratio that the space is diminished. Although having an appreciable and unalterable weight, it is always many times rarer than any liquid or solid; and when pure it is always invisible, tasteless, and scentless.

The *visible* matter, popularly called *steam*, must be carefully distinguished from *steam proper*, or the *aeriform* state of water. The cloud, or smokelike matter alluded to, is really not an air or vapour at all, but a dustlike cloud of minute bodies of *liquid* water, wafted by a current either of true steam, or, more frequently, of mere moist air. Thus the surface of any watery liquid about 20° warmer than the super-

incumbent air (however warm or cold that may be) rapidly gives off true steam, which is invisible, but which no sooner mixes with the colder air, than much or most of it is temporarily recondensed into water, collecting into myriads of minute globes, separately far too small to be seen, but reflecting each a point of light, the millions of which points make the space through which they are diffused appear like a cloudy body, more or less white according to their abundance; just as a space dusted with suns presents the appearance which astronomers call a *nebula.* That these minute bodies, although so much heavier than air or steam, should be carried up, or at least kept from falling, by such very gentle currents thereof, need not surprise us when we remember that water is two or three times lighter than *carbon*, which, in a similar state of division, forms ordinary smoke, and is so readily carried up by the hot gases from a fire. Even glass or marble may easily be pounded fine enough to rise with the gentlest imperceptible currents, and put on all the appearances of this *water smoke*, as it might be called; and although these all eventually fall again, so does a portion of the water, *very often*, in the form of rain from the funnel of a steamer, although in general it disappears by a reconversion into vapour as it spreads through a greater quantity of air. But the watery particles are really very much lighter than has here been supposed, as it is demonstrable that, in all artificial and nearly all natural clouds, they are *hollow*, in fact, *bubbles*, having a shell of extreme thinness compared with their diameter. In natural clouds this has been seen by the naked eye, Saussure having once on the Alps been surrounded by these bubbles or vesicles, which were as large as peas; and it is certain that the same structure exists in clouds generally, because were its water in the form of mere spheres or drops, however small, a screen thereof viewed by a spectator with his back to the sun would always present the same phenomenon as falling rain or spray in the like position, and indeed, generally, a more intense *rainbow* would be seen in proportion as most cloud is more *opaque* than rain, or occupies with its globules a greater portion of the whole space through which it is diffused. Not only does the non-production of any such effect in ordinary clouds and mists enable us to infer the hollowness or *vesicular* nature of their globules, but similar reasoning from the optical phenomena which they *do* present will inform us of the very size, form, and proportions, of these minute and inaccessible objects. Thus, from the concentric coloured circles, called *coronæ*, seen round the sun and moon, when viewed through those light varieties of clouds called *cirri*, and round a candle when viewed through the light haze which is formed in an air-pump-receiver suddenly exhausted, it is known that the cloud vesicles in these cases must be of a certain very uniform diameter, calculable from the measures of the coloured circles, and found by Newton, on one occasion, to be $\frac{1}{500}$th, on another about $\frac{1}{300}$th of an inch. And where a cloud does not produce these circles, as most do not, their sizes must be various and mixed. From the colours, too, given by different kinds of mists to the sun's direct light, making his disk appear golden, orange, blood-red, or, very rarely, rose-red, the thickness of the shells of the vesicles may be inferred, and found to be from $\frac{1}{120000}$th to $\frac{1}{80000}$th of an inch, and more or less uniform as the colour is more or less decided; while the mixture of vesicles of various thicknesses will, like most natural clouds, impart no colour, but only diminish the light by stopping all, the coloured rays equally. The phenomena of *halos*, again, show that a cloud or mist may consist of fine dust of *ice* as well as of water; the varieties of these appearances being all explained by such a crystalline substitute for the ordinary globules, and even enabling us to discover the very shapes of the crystals.

Hence we see that there are at least *seven* different mechanical forms of the matter of ice, water, or steam; three modifications of its solid, three of its liquid, and only one of its aeriform state:—

In the solid state.	1. Ice. 2. Snow. 3. Ice-smoke, or Halo-producing cloud.
In the liquid state.	1. Water. 2. Non-vesicular, or Rainbow-producing cloud, or Spray. 3. Vesicular or common cloud.
In the aeriform state.	1. Steam.

The density of steam, properly so called, is less than that of air under like circumstances; and the relations between these densities, and, perhaps, those of all aeriform bodies, are very curious on account of their commensurability by simple whole numbers, which was one of the most important discoveries of the late Dr. Dalton, "pointing," says Sir J. Herschel, "to a class of phenomena of a remote and singular kind, and of a very high and refined order," viz. "such as consist in observed relations among the data of physics, which show them to be quantities not *arbitrarily* assumed." It is not a little strange that after all the fruitless attempts of philosophers, from Pythagoras down to Kepler, to discover such relations in the measures and motions of the heavenly bodies, in which we should now as little anticipate them as in the areas of islands, or curvatures of coasts, the only seemingly real instances of such a designed simplicity of measure should now be found in the wholly unexpected field of chemistry. The matter of steam, or that which in its different states we call steam, water, or ice, is a compound of two bodies, which, as far as is known, are simple. Always just $\frac{8}{9}$ths of its weight are oxygen, and $\frac{1}{9}$th hydrogen, (the proportion of the former being much greater than in any other known compound, except the very curious and unstable artificial one of 16 oxygen with 1 hydrogen). Now, when these elements are separated, we know them only in the state of gases, neither having been liquefied by any producible pressure, even in the extremest artificial

cold; and the hydrogen gas alone occupies just *as much* space as the whole compound does in the form of steam, at the same temperature, and confined by the same pressure; while the oxygen, although eight times as much, occupies just *half* that space; so that these two gases separate, or merely mixed like those of the atmosphere, fill *once and a half* the space that they do when combined, and in the most expanded state of their compound, viz. steam. This has been found by comparisons of its specific gravity, but when once found, it now enables us to explain, and thus to remember the specific gravities easily; thus:—

One measure of hydrogen, weighing 1 lb. or oz., and
Half a measure of oxygen, weighing 8 lbs. or oz., make

One measure of steam, weighing 9 lbs. or oz.

so that, at equal temperatures and pressures, steam weighs nine times its own bulk of hydrogen, or an eighth more than half its bulk (*i.e.* $\frac{9}{16}$ths of its bulk) of oxygen; or the densities of these three bodies are as the numbers 1, 9, 16.

But in order to compare the density of steam and air, which, omitting its steam, we have seen to consist of oxygen and nitrogen, in the proportions, by weight, of 22 to 77, or 2 to 7; we must next observe that the density of nitrogen is 14 times that of hydrogen at equal temperatures and pressures, or just seven-eighths that of oxygen in like circumstances. Hence 7 lbs. of nitrogen will occupy just as much space as 8 of oxygen, or four times as much as the 2 lbs. thereof with which they are naturally mixed. Therefore, the 77 parts of azote, and 22 of oxygen, *by weight*, are, *by measure*, just *four* measures of nitrogen to *one* of oxygen. If then we call the density of hydrogen, the lightest known body, 1, and, consequently, that of azote, 14, and of oxygen, 16, that of dry air must be between these two numbers, but four times nearer to 14 than to 16, and this is $14\frac{2}{5}$, or 14·4; or, we may add the weight of the single measure of oxygen, called 16, to that of the 4 measures of nitrogen, or 4 times 14, and the sum 72 being the weight of 5 such measures of air, the weight of one must be 14·4. So that dry air is heavier than nitrogen, as 35 to 36, and lighter than oxygen, as 9 to 10; and, lastly, by comparison with steam, this 14·4 is to 9 (the density of steam on the same scale) as 8 is to 5; or the densities of dry air, and of steam equally hot, and equally pressed, are as 8 to 5; and the density of *all* steam, whatever its temperature or pressure, has been measured by the best experimenters as *five-eighths* that of dry air of that same temperature and pressure. It has been found so even to the fourth decimal.

The simplicity and interconnexion of these numbers, relating to the five commonest bodies in nature, makes it easy to impress them on the memory. The lightness of steam compared with the other ingredients of air explains why the dampest air is, under like temperature and pressure, the rarest; and, in some measure, why the barometer is lower or indicates less pressure usually in wet weather than in dry, which, however, is a more complex subject than is commonly supposed, and cannot here be fully explained.

It has been stated that the mechanical properties of steam are identical with those of air; and, indeed, as long as it remains steam, even the numerical measures of the effects of heat and pressure on those properties, are supposed to be alike for all aeriform bodies. For, 1st, with regard to *pressure* acting alone (*i.e.* supposing temperature unchanged), the bulk of a given confined portion of steam or any air, is, as far as experiments have gone, inversely as the elasticity or resistance to compression; so that if, for instance, half the confining pressure be removed, the steam, or gas, expands into double the space it before filled, and, of course, becomes only half as dense; and if, on the other hand, the pressure were doubled, it would be compressed into half its former bulk, and thus become twice as dense, as well as twice as elastic. This is expressed then, by saying that (other things being equal) the density varies as the elasticity; and it is called the law of Boyle or of Mariotte, having been independently established by the experiments of both those philosophers in the seventeenth century, soon after the fundamental discovery of atmospheric pressure by Torricelli. [See AIR.—BAROMETER.]

Again, with regard to the effects of *temperature* alone (*i.e.* supposing the confining pressure to be constant) it is thought to have been established independently by Dalton and Gay Lussac, at the beginning of this century, that (unlike solids and liquids, which have each its own law of expansion and contraction) *all* airs and vapours are affected *equally* by any given change of temperature, and that the rise from the freezing point to the common boiling point of water, causes *any* portion of them, confined by a constant pressure, to expand *three-eighths* of its bulk at the former point. Moreover the expansion of air is *theoretically* taken as the measure, or rather, the definition of degrees of temperature; that is to say, if we call the freezing point 0°, and the common boiling point 100° (as in those countries where the centigrade scale is used), then 50° means that temperature to which, if *air* be heated from 0°, it has expanded half as much as in heating to 100°. So also on our scale, where the freezing point is made 32°, and the boiling, 212°, as 8 measures of air at the former point become 11 at the latter, when we speak of 92°, or of 152°, we mean the temperatures at which the 8 measures of air would have become 9 and 10 respectively. And as the degrees, into which we divide the whole interval between freezing and boiling, are 180, each degree means such a change of temperature as will expand air $\frac{1}{180}$ of $\frac{3}{8}$ of its bulk at freezing, that is, $\frac{1}{480}$ of its bulk at freezing, or $\frac{1}{660}$ of its bulk at 212°.

We need hardly observe, that this is a most imperfect measurement, or rather no measurement of *temperature* at all. The very idea of measurement implies that equal numbers of our units, whether

called feet or degrees, &c. should express equal quantities of the thing measured. But here the 60° from 32° to 92°, and the 60° from 152° to 212°, for instance, cannot be shown to be equal intervals of temperature, and we have no reason whatever to suppose them so. They only express equal expansions of air, and degrees thus divided can only rightly be called degrees of *air expansion*, and not degrees of *temperature*. To call them so is incorrect, if there be any established and precise meaning attached to the word temperature when used apart from degrees, and this we believe there is. We call two bodies equal in temperature when, being kept in contact, no heat tends to pass from one to the other. It follows from this that equal intervals or differences of temperature can only mean such as one and the same heat would produce in equal bulks of the same substance in the same state. And twice or ten times any difference of temperature must mean such difference as that same heat which produced the smaller difference, would produce in a half or a tenth part of the matter in which that smaller difference was produced. Thus 1° of temperature must be the difference that would be made in 10 pints of water by the adding or taking away the same heat that raises 1 pint of the same water 10°. And thus, if we have fixed on any two identifiable temperatures, and called them 0° and 100°, then 50° means the temperature produced by mixing equal bulks of the same fluid, no matter what, at 0° and at 100°. And to call any other temperature than this a temperature of 50°, is a fallacy. Yet we always call by this name a temperature essentially different, viz. that at which some particular substance, as air or even mercury, would expand to a mean between its bulk at 0° and at 100°. This point is not 50° of temperature, but 50° of *expansion;* and the common thermometer only measures or compares expansions, although, of course, it *identifies* temperatures, because a given degree of expansion of a given substance always belongs to a certain identical temperature. Newton sanctioned this kind of thermometer scale because the use of the instrument did not then extend beyond mere identification, and the important science of heat did not exist and could hardly be anticipated. But great confusion has arisen in most matters connected with heat, by persisting in this first crude substitute for a measure of temperature; quite needlessly in scientific researches, because although a true scale thereof, divided on the above principle, might be troublesome to make at first, it might, when once made, be multiplied, with any enlargement or reduction, just as easily as any of the scales of unequal parts placed on drawing and slide rules, and would be applicable to all thermometers of the same fluid as that of the original thermometer, with the single proviso that their tubes be of equable bore from end to end, which is just as necessary in the present division by equal parts.

Some late experiments of Regnault and others have made it doubtful whether the Daltonian law applies to vapours: that is to say, whether they expand for *small* increments of temperature precisely as gases do, and Mr. C. W. Siemens has observed the following five expansions of steam heated from 212° upwards. If we call the original bulk of both steam and air 660 parts, so that the air would expand *one* part more for each interval called a degree, the steam expanded 66 parts by a rise of 7°;

132 „ by a rise of 35°;
198 „ by a rise of 75°;
264 „ by a rise of 120°;
330 „ by a rise of 165°; or that

rise which would expand *air* 165 parts. Thus the difference between the behaviour of steam and air seems to diminish as the interval of temperature increases, but still to be as 2 to 1 in this case, where the steam-expansion of ½ answers to an air-expansion of only ¼. Such determinations, however, are extremely delicate and difficult, as we shall see.

But in any case, it follows from Mariotte's law that in whatever proportion a mass of air, gas, or vapour might be expanded by a given rise of temperature, were it confined by one unvarying pressure, in that same proportion will its elasticity or expansive force be increased by that same rise, if it be rigidly confined so as to occupy always the same space. For, of course, a gas or vapour cannot exhibit expansion and contraction by heat and cold unless it be confined in part by a liquid or other yielding surface. Now, whatever rise of warmth would in this case add a given fraction, say ⅛th, to the space it fills, still opposing the same confining pressure, or preserving the same *elasticity*, that same rise of warmth will, if the vapour be confined to the same *space* as before, add ⅛th to the pressure required so to confine it; or, if it be wholly enclosed in an unyielding vessel, will add ⅛th to the force with which it tends to burst the vessel.

We now come to the properties relating to the change of state from water into steam, and *vice versâ.* Whether there be any temperature below which a given substance, water, for instance, could not exist in the state of vapour, we have no means of deciding. Some experiments by Faraday seem to prove that mercury does not evaporate at all in our winter temperatures [see MERCURY], but we know of no such limit, in the case of aqueous matter. Snow and ice will not, any more than water, leave any space that is open to them empty: they will fill it with steam, and, if the space be large enough, will pass entirely into steam, however low the temperature, at least so far as we know. But, according to this, a larger space is necessary the lower the temperature, because the colder it be the less becomes the tension of the water or of the snow; by which word *tension* we mean the tendency to emit vapour, and of course the vapour can only accumulate until its pressure on the water or the snow just balances this tendency, when all evaporation must cease till there is either more space allowed or more heat introduced. [See EVAPORATION.] Hence, whatever be the space, large or small, steam can only, at a given temperature, attain a certain density and pressure neither greater nor less. It

requires a certain space to exist in *as steam*, and although we may compress it into less than this space, this can only be by a portion of it becoming water or ice, leaving the aeriform portion still of the same density and elasticity. On the other hand, if the space be enlarged (without change of temperature), more will pass from the solid or liquid state into the vaporous, until the same pressure as before is maintained, or all the water be evaporated. When this has happened, of course any further space allowed will reduce the density and pressure of the vapour according to Mariotte's law, but as long as the space is *saturated*, or water be present, and prevented from evaporating, the density of vapour depends only on the temperature, and such is called *saturated* steam, and is the only kind employed to work steam-engines. Steam allowed to expand beyond this bulk, or the smallest which it can occupy without condensation, or, in short, any steam in which water will evaporate, is called *sub-saturated* steam, and such is all the steam commonly mixed in the atmosphere, for otherwise nothing once wetted would dry—no water would evaporate. An enclosed body of saturated steam may also be brought into the sub-saturated state without expansion or any change of density, simply by raising its temperature, for although this will increase its pressure, it will not do so to the same extent as if water were present, and if water were now introduced, it would evaporate, until the steam became saturated, and of a much higher pressure. Hence subsaturated steam, when artificially produced, is called by engineers *overheated*, *superheated*, or *surcharged* steam, *i. e.* charged with more heat than is necessary to maintain its elasticity, or with as much heat as would maintain more matter at that same elasticity. We prefer the term *subsaturated*, as the others are hardly intelligible when applied to steam of low temperature, as that existing in the air. We might also call it *dry* steam.

It is a very remarkable fact, discovered by Dalton, that these limitations to the evaporation of water, at any given temperature, can only arise from the pressure of its own vapour. No amount of pressure of air or any other gas can stop or prevent the evaporation of water, but can only retard it, so as to affect the *time* occupied in evaporating, but not the *quantity* of vapour sent forth to saturate the space. Thus if water, more than sufficient to saturate a cubic foot of space at a certain known temperature, were introduced at that temperature into an empty vessel of the capacity of a cubic foot, and also into a similar vessel of air ever so dense; although the vacuum would be much *sooner* saturated than the air, yet both, when saturated, would contain equal weights of steam; and whatever might be the pressure of steam in the vessel containing steam only, the other vessel would have that same pressure *plus* that of the air; so that if the latter were 15 lbs. per square inch, and that in the vessel of steam only were 1 lb. per inch, that in the other vessel would be 16 lbs. per inch.

Thus, although the tension, or tendency to evaporate, of water at common temperatures is very small compared with the atmospheric pressure, that pressure does not prevent its evaporating; while a pressure only just equal to its tension, if arising from the *vapour* in the air, would stop that evaporation altogether.

But when water is heated to that temperature at which its tension equals the whole pressure of both air and vapour on its surface, it begins to emit steam, not only from its surface as before, but from all parts of its depth; and this we call *boiling*. [See EBULLITION.] The boiling-point of any liquid, therefore, means the temperature at which its evaporating tendency equals the common pressure of the atmosphere, or the lowest temperature at which its vapour can have the elasticity of common air. And as the pressure at the earth's surface varies in temperate climates, between 28 and 31 inches of the barometric mercury, of course no liquids have always the same boiling-point, but all their boiling-points are higher or lower as the barometer rises or sinks. As a particular boiling-point of water forms one of the defining points for reckoning temperatures, on every thermometric scale, it becomes necessary to fix on a certain pressure (best defined by a certain height of the barometer) under which pressure the boiling-point shall be taken as 100° or 212°, or whatever number of degrees we denominate the standard boiling-point by. In this country, the pressure for this purpose is fixed at 30 inches of mercury, so that the standard boiling-point, or 212°, means the temperature at which saturated steam will just sustain a pressure of 30 inches of mercury. We call it *high* or *low-pressure* steam, according as its pressure is greater or less than this; and of course it follows that all high-pressure steam must be hotter than 212°, and all *saturated* low-pressure steam cooler than 212°, though it may, if subsaturated, be as hot as we please.

Many modes have been adopted by experimenters for finding accurately the pressures of saturated steam corresponding to different temperatures above and below the standard boiling-point, but they are all modifications of those contrived by the first investigators of this subject, Dalton, Robison, and Watt. For low-pressure observations, a barometer has always been formed in Torricelli's original way, by inverting a straight tube of mercury, and dipping its mouth into a cup of the same; but either first wetting the closed end where the vacuum would be, or afterwards sending up a drop of water into it. The mercury will then always stand lower than in a common dry barometer at the same time and place, because the steam in the top of the tube presses so as to balance a portion of the external air-pressure; so that the difference between the mercurial columns in this and the dry barometer will be the exact height of mercury the steam would support, if acting against a vacuum. Different temperatures were obtained by surrounding the upper part of the tube with a vessel of water, or snow or freezing mixture, and the results by many observers are collected in the following table:—

Synopsis of Experiments on the Force of
LOW-PRESSURE STEAM.
The temperatures reduced to Fahrenheit, and the pressures to English inches of mercury.

TEMP.	PRESSURE.	AUTHORITIES.
− 3·2	0·054	Gay Lussac.
0	·08	Dalton.
+ 10	·12	Dalton.
20	·17	Dalton.
24	·17	Ure.
32	·26	Dalton: ·2 Ure; ·16 Southern.
34	·28	Dalton.
36	·3	Dalton.
38	·32	Dalton.
40	·34	Dalton; ·25 Ure; ·1 Robison.
42	·37	Dalton; ·23 Southern.
43·25	·3	Dalton; ·05 Betancourt.
44	·4	Dalton.
46	·43	Dalton.
48	·46	Dalton.
50	·49	Dalton; ·36 Ure; ·2 Robison.
52	·52	Dalton; ·35 Southern.
54	·56	Dalton.
54·5	·435	Dalton; ·17 Betancourt.
55	·416	Ure; ·15 Watt.
56	·59	Dalton.
58	·62	Dalton.
60	·65	Dalton; ·516 Ure; ·35 Robison.
62	·69	Dalton; ·52 Southern.
64	·73	Dalton.
65	·63	Ure.
65·75	·63	Dalton; ·35 Betancourt.
66	·77	Dalton.
68	·82	Dalton.
70	·87	Dalton; ·726 Ure; ·55 Robison.
72	·92	Dalton; ·73 Southern.
74	·97	Dalton.
75	·86	Ure.
76	1·03	Dalton.
77	91	Dalton; ·65 Betancourt.
78	1·09	Dalton.
80	1·16	Dalton; 1·01 Ure; ·82 Robison.
82	1·02	Southern.
85	1·17	Ure.
88·25	1·29	Dalton; 1·05 Betancourt.
90	1·59	Dalton; 1·36 Ure; 1·18 Robison.
92	1·42	Southern.
95	1·64	Ure.
96	1·95	Dalton.
99·5	1·82	Dalton; 1·52 Betancourt.
00	2·12	Dalton; 1·86 Ure; 1·6 Robison.
02	1·96	Southern.
105	2·1	Ure.
110	2·79	Dalton; 2·456 Ure; 2·25 Robison.
110·75	2·54	Dalton; 2·15 Betancourt.
112	2·66	Southern.
115	2·81	Ure.
118	2·68	Watt.
120	3·63	Dalton; 3·3 Ure; 3· Robison.
122	3·58	Southern; 3·5 Dalton; 2·92 Betancourt.
125	3·83	Ure.
130	4·71	Dalton; 4·366 Ure; 3·95 Robison.
132	5·07	Dalton; 4·71 Southern.
133·25	4·76	Dalton; 4· Betancourt.
135	5·07	Ure.
140	6·05	Dalton; 5·77 Ure; 5·15 Robison.
142	6·1	Southern.
144·5	6 45	Dalton; 5·5 Betancourt.
145	6·6	Ure.
150	7·73	Dalton; 7·53 Ure; 6·72 Robison.
152	7·9	Southern.
155	8·5	Ure.
155·75	8·55	Dalton; 7·55 Betancourt.
160	9·79	Dalton; 9·6 Ure; 8·65 Robison.
162	10·05	Southern.
165	10·8	Ure; 10·68 Dalton.
167	11·25	Dalton; 10· Betancourt.
170	12·31	Dalton; 12·05 Ure; 11·05 Robison.
172	12·72	Southern.
173	13·18	Dalton.
175	13·62	Dalton; 13·55 Ure.
178·25	14·6	Dalton; 13·25 Betancourt.
180	15·38	Dalton; 15·15 Ure; 14·73 Watt 14·05 Robison.
182	16·01	Southern.
185	17·	Dalton; 16·9 Ure.
189·5	18·8	Dalton; 17·5 Betancourt.
190	19·	Ure and Dalton; 17·85 Robison.
192	20·04	Southern.
195	21·1	Ure.
200	23·6	Ure; 23·51 Dalton; 22·6 Robison.
200·75	24·	Dalton; 22·35 Betancourt.
202	24·61	Southern.
205	25·9	Ure.
210	28·88	Ure; 28·82 Dalton; 28·65 Robison.
212	30·00	*Datum of Measurement.*

It has been found in these experiments that if a minute portion of soda, or of any salt soluble in water and incapable of rising in vapour with it, be allowed to rise to the top of the mercury, the column immediately ascends, so as to indicate a diminished pressure of steam, although the soda has not even touched it, but remains covered by the layer of water on the top of the mercury. This shows plainly that the elasticity depends not merely on the temperature and the nature of the vapour, which are both unchanged, but on the nature of the *liquid*. Because the soda has an affinity for water, and cannot accompany it into a vaporous state, it tends to restrain the water from evaporating; and this tendency is a measurable force, and here measured, for it partly balances the tension of the water, or its tendency to emit steam, and thus makes the steam-emitting tension of a solution of soda measurably less than that of pure water at the same temperature; so that although both emit equally pure steam, identically alike, yet the solution cannot support, at the same temperature, so great a pressure of steam as the water supported, and thus part of the steam returns into the liquid. Of course, as the difference remains at all temperatures, the solution must always be made hotter than pure water need be, in order to give steam of the same elasticity, so that, ascending to that which will balance the atmosphere, we shall find the *boiling-point* of the solution higher than that of water under like pressure. This is well known to be the case with all solutions of bodies not evaporable with the water. The common boiling-point of sea-water is 215°, and of brine 222°.

The same experiment shows the nature of the action of *desiccants*, or bodies that absorb steam from the air, and so render it drier. The solution of soda acted thus on the steam to a certain extent, and if removed, would leave it in the state of subsaturated steam, capable of taking up more water if pure water were then introduced. A piece of dry soda would have had a still greater effect, and it is by keeping air in contact with sulphuric acid or with the most deliquescent salts, such as muriate of lime, that it is reduced most nearly to dryness.

When gases or vapours have a very greedy attraction for water, and form with it liquids less evaporable than pure water, they exhibit to us this steam of the atmosphere in a very striking manner. Muriatic acid gas has these properties, [see HYDROCHLORIC ACID,] and on coming into the ordinary air, it instantly picks

out the aqueous vapour, and, forming therewith a compound less volatile than either body separately, this compound is condensed into minute drops or vesicles, so as to form a *cloud*, till by spreading through greater space, usually far from saturated with steam, they again disappear into vapour. But were the air already nearly saturated, the cloud must fall in a rain of dilute acid, as is often the case from the chimneys of the manufactories of soda from common salt. [See SODIUM.] As the muriatic acid of commerce is always giving out this gas while open to the air, it appears to smoke, and the same explanation applies to the smoking of other cold bodies, as the Nordhausen sulphuric acid, &c. Ammonia does not smoke, although it gives out as much gas as any of these bodies, and that gas as greedily unites with steam. The reason is, that the compound here formed has a *lower* instead of a higher boiling point than the steam alone, so that whatever density of common steam the temperature could support, it can still more readily support that density of ammoniacal steam, and therefore it remains uncondensed and permanently invisible. For the same reason strong alcoholic liquors, in being boiled, give off no visible cloud. The alcohol vapour combines with the steam of the air, but both remain invisible.

All clouds are in fact similar to what, when occurring in liquids instead of airs, is called a *precipitate*. Two liquids mix and so act as to evolve an insoluble solid, which was previously dissolved or liquid. It either falls down in a fine powder, or is dissolved by some further action, so as to be seen only as a temporary milkiness. In the same way two transparent currents of air, or air and steam, may, on meeting, produce for a time, or permanently, a lower temperature than can support the amount of vapour in both together, and then some of it immediately liquefies in the finely divided state which we call *cloud*, and eventually falls in rain, unless re-dissolved or rather re-vaporized by obtaining either more heat or more unsaturated space for diffusion,—and this all our miniature artificial clouds commonly do.

Of course any subsaturated steam, as that of the atmosphere, may be cooled down to some particular lower temperature at which it would be saturated, and ever so little below which, a portion of it would be liquefied. The temperature at which any subsaturated steam would thus become moist steam, is called its *dew-point*, because a solid cooled down to this point would condense the steam upon its surface in the form of dew. It is wholly immaterial to this effect whether the steam be alone or mixed with air to any extent. Hence the observation of this point is the best means known for ascertaining the exact amount of steam in the air at any time. Daniell's hygrometer is founded on this principle. [See EVAPORATION, Fig. 895.]

For observations on the elasticity of *high-pressure* steam, closed boilers of the requisite strength have been fitted with mercurial gauges, that is, tubes bent like the letter U, but with unequal arms, the shorter inserted into the boiler, and the longer open to the air, so that the steam pressing on mercury, in the bend of the tube, might be balanced by a column of mercury poured into the higher arm. The chief results are embodied in the following table:—

Synopsis of Experiments on the Force of
HIGH-PRESSURE STEAM.

The temperatures reduced to Fahrenheit, and the pressures to English inches of mercury.

TEMP.	PRESSURE.	AUTHORITIES.
212	30·00	
216·6	33·4	Ure.
220	35·54	Ure; 34·95 Taylor; 35·18 Dalton; 35·8 Robison.
221·6	36·7	Ure.
223·25	37·	Betancourt.
225	39·11	Ure; 37· Watt.
226·3	40·1	Ure.
230	43·1	Ure; 41·51 Taylor; 44·6 Dalton; 44·5 Robison.
230·5	43·5	Ure.
232	44·4	Arsberger.
234	45·00	French Academicians.
234·5	46·8	Ure; 46·8 Betancourt.
235	47·22	Ure.
238·5	50·3	Ure.
240	51·7	Ure; 50· Taylor; 49· Watt; 53·45 Dalton; 54·9 Robison.
242	53·6	Ure.
245	56·34	Ure.
245·75	58·	Betancourt.
248·5	60·4	Ure.
249	59·1	Arsberger.
250	61·9	Ure; 60· Franklin Institute; 59·12 Taylor; 66·8 Robison.
250·3	60·00	Southern.
250·5	60·00	French Academicians.
255	67·25	Ure.
257	72·1	Betancourt.
260	72·3	Ure; 70·1 Taylor; 80·3 Robison.
261	68·	Watt.
263·8	75·00	French Academicians.
265	78·04	Ure.
268·25	85·85	Betancourt.
270	86·3	Ure; 82·5 Taylor; 94·1 Robison.
272	88·9	Dalton.
272·5	82·	Watt.
274	88·8	Arsberger.
275	93·48	Ure.
275·2	90·00	French Academ. and Franklin Inst
279·5	98·	Betancourt.
280	101·9	97·75 Taylor; 105·9 Robison.
285	105·00	French Academicians.
285·2	112·2	Ure.
290	120·15	Ure; 114·5 Taylor.
291·5	120·00	Franklin Institute.
293·4	120·00	Southern.
293·7	120·00	French Academicians
295·	129·	Ure.
300·	139·7	Ure; 133·75 Taylor.
300·3	135·00	French Academicians.
304·5	150·00	Franklin Institute.
305·	150·56	Ure.
308·8	150·00	French Academicians.
310·	161·3	Ure.
312·	166·25	Ure.
314·24	165·00	French Academicians.
315·5	180·00	Franklin Institute.
320·	179·4	Taylor.
320·4	180·00	French Academicians.
322·	176·	Arsberger.
326·3	195·00	French Academicians.
326·5	210·00	Franklin Institute.
331·7	210·00	French Academicians.
336·	240·00	Franklin Institute.
340·	231·	Dalton.
343·6	240·00	Southern.
352·5	270·00	Franklin Institute.
358·8	300·00	French Academicians.
366·85	330·00	French Academicians.

TEMP.	PRESSURE.	AUTHORITIES.
372·	325·	Arsberger.
374·	360·00	French Academicians
380·66	390·	French Academicians.
383·8	450·	Franklin Institute.
386·94	420·	French Academicians.
392·86	450·	French Academicians.
398·5	480·	French Academicians.
403·83	510·	French Academicians.
405·	600·	Franklin Institute.
408·92	540·	French Academicians.
413·8	570·	French Academicians.
418·5	600.	French Academicians.
423·	630·	French Academicians.
427·3	660·	French Academicians.
431·5	690·	French Academic.; 620· Arsberger.
435·6	720·	French Academicians.

Dr. Ure's experiments were made with the following simple apparatus. Into the globular vessel or heater, which for temperatures above 212° contains *oil*, (the boiling point of which is nearly 600°,) the bulb of the thermometer T, Fig. 2034, is made to dip, and through another opening is fixed the sloping part of the bent glass tube, which forms at once the boiler, steam-chamber, and barometric gauge. The water for generating the steam consists only of a drop enclosed between the mercury and the closed end of the tube, and as the whole of both the water and steam are always included in the piece of tube within the oil-vessel, they have wholly one temperature, exactly that of the thermometer bulb; while the mercurial column in the guage being almost all outside the vessel and unaffected by the heat, no uncertainty arises from its expansion. Two marks are made on the tube by twisting a fine wire round it at the point the mercury stands at when perfectly level in both arms, and heat being applied by a lamp under the globe, more mercury is gradually poured into the open top, until its inner level, within the oil, is brought to its original place, and then the height of mercury above the mark on the upright portion evidently measures the excess of the steam pressure above that of the atmosphere, at the temperature shown by the thermometer at that moment. The gauge tube is kept strictly vertical by a groove in an upright wooden post, and for the fine experiments of the French and the Franklin Institutes, was required to be above 60 feet high. The French apparatus was applied to determine another point of importance. By compressing *air* instead of steam, and carefully measuring the space occupied by a known weight of it, they found the density so nearly proportional to the height of mercury compressing it, that the differences were within what might be expected from errors of observation, up to the extent of their gauge, or 24 atmospheres' pressure. This is the highest to which the law of Mariotte has yet been experimentally verified, though air is said to have been compressed until it was denser than water, which by this law would require above 800 atmospheres' pressure, and makes it extremely improbable that the law extends so far. Its proved extension to 24, however, in the case of air, has led for the present to a sort of tacit assumption that it may be relied on to that extent in steam also, or even in all elastic fluids until the contrary be proved.

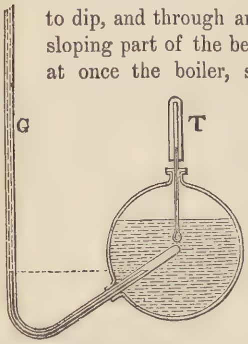


Fig. 2034.

In a first glance over the preceding tabulated numbers we seem to see a rule connecting the temperature and elasticity, viz. that for equal *intervals* of temperature, the elasticities increase by equal *ratios*, so that whatever number of degrees may double the elasticity, for instance, or increase it from half-an-inch to one inch, the same number nearly will again double it or increase it from 1 to 2 inches, from 2 to 4, &c.; and Dalton, who first made extensive observations of this kind, was led by his earliest ones on low pressure steam to assume this as a law. Further examination, however, of the tables will soon prove to us, as further experiment proved to him, that such a rule, from whatever part of the series we take it, will give, when extended to higher temperatures, too rapid an increase of elasticity, and on the other hand, too slow a decrease in those below the range from whence the rule was derived. Hence, Dr. Ure contrived a modification of the rule, which is found to give a useful approximation to the pressure at any temperature not more than 60° or 80° above or below boiling, which includes all cases now practically occurring in the steam engine, and involves almost nothing to tax the memory. The ratio between the elasticities at boiling and at 10° above it, is as 1 to 1·23, three figures easily remembered. Now the increase for the next 10°, or from 222° to 232°, is as 1 to 1·22; for the next step of 10° it is as 1 to 1·21; for the next as 1 to 1·20, and so on. The same series, without interruption, may be applied to the descending steps of 10° below boiling, the first step from 212° to 202°, diminishing the pressure as 1·24 to 1, the next as 1·25 to 1, and so on. It is thus easy by interpolating between the numbers thus obtained for the steps of 10°, to approximate the pressure for any intermediate degree as nearly as can be required in the absence of the above tables, and almost as nearly as the most elaborate formulæ yet contrived by the mathematicians have done.

These formulæ, which are very numerous, differing rather in their constant numbers than in their form, we do not think it necessary to explain, because no one pretends that any of them represent the law of nature. They have a complexity and arbitrariness totally unlike any natural law, and moreover, each is only applicable, like the above, within certain limits, above or below which it grows more discordant with the observations the further it is extended, and has therefore to be replaced by some other rule found more applicable to that part of the scale. It is as if we were attempting to fit the varying curvature of some vast natural line, with curved templates or rulers of different curvatures, each of which seems to fit exactly some limited portion, but soon betrays its non-correspondence with nature when continued far either

way. That a law doubtless as simple as other natural laws should still be concealed in this great series of measurements, when in general even three or four accurate measures of such mutually dependent quantities cannot be made without at once displaying their law of dependence, (as when Kepler, from the relations of distance and periodic time in *two* planets, for instance, was led to the general law connecting these two elements in them all,) and that it should even remain thus concealed, after all the mathematics brought to bear on them by Laplace, Arago, Biot, Prony, Ivory, Tredgold, and many calculators of hardly less eminence, may seem strange at first, but is really just what might be expected, if we remember what the quantity here miscalled the *temperature* really is. As already pointed out, it represents no measure of a simple natural quality or quantity, (such as heat or density or pressure,) but only of one peculiar and probably complex *effect* of heat. It is a mode of comparing and identifying temperatures, just in the way that degrees of moisture were once compared and identified by their relative effects in lengthening or contracting a hair, or just as the mineralogist still distinguishes degrees of hardness, by the ability to scratch or to be scratched by certain conventional standard substances. We might as well weigh bodies by measuring the extent to which they will bend a spring of a given identifiable stiffness, and this would answer all the ends in regard to weight, that the thermometer or the above contrivances were intended to do, and indeed do in their common every day use, for mere identification. But we could not *weigh* with a spring-balance (*i.e. measure* weights) if its degrees were formed with reference only to spaces on the scale, or expressed equal amounts of bending. We might *call* the numbers on such a scale indeed the weights of bodies, (just as we call those on the thermometer scale their temperatures,) but any inquiry involving precise relations of real weights would expose the fallacy in that case, as in this. We should be a long time learning from those numbers the law of *chemical equivalents* for instance, twist and torture them as we might. Now the laws of heat are sought from precisely such data as these would be. Why expect *any* equation simple enough to be discovered by chance, between two quantities so remotely connected as the elasticity of steam and the difference of the expansions of mercury and glass by the temperature of that steam? The first application to these measures of a real *thermo*metric scale,—one of equal degrees of *heat*, instead of equal degrees of *expansion*, —will probably at once make evident the law that has baffled and must baffle these, as we think, ill-considered exercises of misapplied mathematics.

It is conceivable, too, that the relation between the temperature, truly measured, and the *density* of the saturated steam, may be simpler than between the temperature and the elasticity. As doubts are now thrown on the applicability of Dalton's and Gay Lussac's law of gaseous expansion to this vapour, we can no longer, as heretofore, look on the densities as calculable from the other two elements, temperature and elasticity, when the density for one particular value of them is once determined; and direct measures of the density are so delicate and difficult, that we fear a series of them will long be a desideratum. On the supposition, however, of steam following strictly the same law established by those philosophers in the case of air and several gases, so that any two of these three elements being given the third would be known, the following table has been computed, to show the general march of the density and other chief properties of saturated steam for an extreme variety of temperatures.

Properties of Steam and Water at Different Temperatures.

Temperature Fahrenheit.	Pressure in inches of mercury.	The same in atmospheres.	Volume of the water.	Volume of the same in steam.	Expansion in evaporating.	Density compared to air of the same temperature.
− 3·2	0·054	1-555th	1·0036	635000·	632722·	1-888th
+10·	·12	1-250th	1·00174	294924·	294412·	1-400th
39·	·33	1-90th	1·00000	112895·	112895·	1-144th
65·	·75	1-40th	1·00144	52855·	52779·	1-64th
100·	2·	1.15th	1·0072	21173·	21021·	1-24th
140·	6·	1-5th	1·0179	7573·	7439·	1-8th
180·	15·	1-half	1·0314	3235·	3136·	·3125
212·	30·	One	1·0433	1700·	1630·	·625
250·5	60·	Two	1·058	900·	850·7	1·25
293·7	120·	Four	1·075	477·8	444·3	2·3
358·8	300·	Ten	1·090	207·8	190·6	6·25
418·5	600·	Twenty	1·122	111·5	99·4	12·5
457·2	900·	Thirty	1·136	77·7	67·5	18·75
486·6	1200·	Forty	1·147	60·2	52·5	25·
510·6	1500·	Fifty	1·155	49·4	42·77	31·25

The corresponding temperatures and elasticities are here taken from Dalton for low-pressure steam, from Dulong and Arago for high-pressure. The fourth column is then calculated thus. The volume of an unit of water at 39° (its point of greatest density) being taken as unity, the space which it would occupy at any other temperature is taken from the observations of Kirwan and Gilpin, up to 212°. But as these measures were made under the constant pressure of one atmosphere, while the water is here supposed subject to the varying pressure of its own vapour only, the correction for this is reckoned from Perkins's experiments on the compression of water, and found not to affect the last decimal here given. Although we have no measures of water at the two temperatures below freezing, it is known under these circumstances to go on expanding by cold, and these volumes have been reckoned by the empirical formula that Dr. Young found to represent very closely the expansions both ways from 39° as far as they had been measured. But in applying Dr. Young's rule above 212°, we find it give a maximum volume at about 360°, above which it makes the water *contract* by heat as fast as it had previously expanded. So anomalous an effect could only be admitted on experimental proof. Until further observations, therefore, had been made, we could only, as a more probable supposition, reckon these volumes by a regular expansion at the rate Gay Lussac measured in the last few degrees below boiling; and then reduce

them for the compression caused by the steam, which, however, only affects the last decimal in the last two numbers. This shows that at 510° we are still far short of the temperature at which water would *cease to expand,* being stopped by the pressure of its own steam, balancing its own tendency to dilate. The next column, headed "Volume of Steam," is based on the number 1,700, which, according to Gay Lussac, represents the space that *one* measure of water at its greatest density will occupy when converted into boiling steam. To obtain the space occupied at any other temperature, we first increase or diminish this inversely as the pressure in the second column, and then increase or diminish the resulting number, by $\frac{1}{660}$th of itself for every degree above or below 212°. For instance, if the 1,700 measures of steam of one atmosphere were to expand without change of temperature, till its elasticity were reduced one-half, it would, by the Boylean law, occupy twice its former bulk, or 3,400 measures; but it would not then be *saturated* steam, but subsaturated, having only half the density and elasticity its temperature could support, and capable of taking up its own weight of additional water. In other words it would be *overheated* steam, having at 212° only the pressure belonging to saturated steam of 180°. It would be like the steam of the atmosphere, a *dry* or *drying* steam, one in which water could evaporate, or wet bodies of its own temperature be dried, and so could any bodies hotter than 180°. But 180° would be its *dew-point,* down to which it must be cooled before any would condense into water, or at which point it would become saturated steam. Hence the same quantity that as steam of one atmosphere filled 1,700 measures, plainly cannot, as *saturated* steam of half an atmosphere, fill 3,400 measures, but to find its new volume we must diminish this 3,400 in the proportion that airs under a constant pressure contract in cooling from 212° to 180°, that is (if the Daltonian law apply here) in the proportion of 448 + 212 to 448 + 180, the volumes being, according to this law, proportional to the temperatures reckoned from 448° below Fahrenheit's zero. We thus diminish it to 3,235, which expresses the smallest space in which 1,700 measures of boiling steam would cool to 180° without depositing any moisture, or the smallest in which one measure of water at 39° could pass wholly into steam at 180°. Or, again, if 1,700 measures of boiling steam could be compressed by an additional atmosphere without any being liquefied, they would, like air or gas, occupy under this doubled pressure only half their former bulk. But it is impossible to compress this or any *saturated* steam ever so little, without liquefying a part, unless we add at the same time heat enough to raise its temperature to the point at which water boils under this increased pressure. Thus we cannot possibly have steam of one atmosphere cooler than 212°, nor steam of two atmospheres below 250½°, (though as much *above* these temperatures as we please.) It follows, then, that the water which at 212° requires 1,700 measures to exist in as steam, must at 250½°, though twice as elastic, require *more* than the half of this,—*more* than 850 measures, in the proportion that air under a constant pressure would expand if heated from 212° to 250½°; and by increasing the 850 in this proportion we obtain very nearly 900 for the smallest space in which 1,700 measures of boiling steam (or one measure of water in its densest state) could be wholly converted into steam of two atmospheres, or of 250½°.

The numbers in the sixth column are found by dividing each of these volumes of steam by the volume which it occupies as water at the same temperature; and those in the last are all ⅝ths of those in the third, because we have seen that *all* steam is probably ⅝ths as dense as air of the same temperature and pressure. This column shows us, that while steam of the high pressures observed by Dulong and Arago is by far the densest aeriform matter known, the steam of low and common temperatures presents the lightest form of matter of which we have any evidence (if that of comets be excepted); that which depressed the mercury of Gay Lussac's barometer in his coldest observation being probably 888 times thinner than air, while even at summer temperatures, in which he contrived with exquisite ingenuity to submit it to actual weighing, it is the lightest body ever weighed, hydrogen having only been weighed at the common pressure, under which it is much denser than saturated steam of 100° Fahr.

As we see that with increase of temperature the liquid and its vapour both tend to approach each other in density, the water becoming expanded and the steam at the same time rapidly denser, so that while ice at zero (supposing it one-tenth rarer than water at zero) requires more than half-a-million times its own space to evaporate in, water at 510° requires only 43 times its space; a question naturally arises whether there be not some higher fixed temperature at which the two forms of this substance would be equally dense, and thus merge into one, the distinction of steam and water no longer existing; or rather a temperature above which water could not exist, but steam, however much compressed, even to the density of water, would remain *permanently* gaseous, as air and hydrogen seem to do at common temperatures. On this point, M. Cagnard De la Tour made some curious experiments, and is said to have heated alcohol and ether, enclosed in glass tubes, to temperatures at which they became wholly vaporous and invisible, in little more than the space they occupied as liquids,—and water in about four times that space, at a temperature about that of melting zinc, above which the experiments were prevented by the solvent power of this liquid becoming so increased as to attack any kind of glass. Supposing the temperature 700°, this would make steam of that temperature 425 times as dense as boiling steam, and, of course, if the Boylean law extend so far, 425 times as elastic as boiling steam (or atmospheric air) would be if heated from 212° to 700°, without change of density, or with neither access of water nor room for expansion. An aeriform body so heated would, by the Daltonian law, have its elasticity increased as 448 + 212 to

448 + 700, or as 660 to 1,148, and by increasing 425 in this ratio we get 739 atmospheres for the pressure probably borne by M. De la Tour's glass tube. This is the nearest approach to the yet unsolved problem of "making water red-hot." It is well-known that in red-hot metallic vessels, it does not touch them, nor become much hotter than 210°, nor produce steam nearly so elastic as the atmosphere. [See EBULLITION.] The luminous film of every hydrogenous flame may be regarded as red or white-hot *steam*, and shows that the rarity or transparency of aeriform bodies prevents their giving, at the intensest degrees of incandescence, so much light as solids give at far lower degrees. In ordinary flames it is the light of incandescent *carbon* only that we use, and it entirely drowns that of the equally hot newly formed steam or carbonic acid.

We have now to explain how it is known, that although steam and water can thus co-exist at almost every measurable temperature, the steam has always, as stated at the outset, more heat than water has. We know that the visible cloud commonly called steam is never so hot as the liquid whence it comes, and will never even scald the hand, although the steam from a boiling kettle will do so, while in its *invisible* state, or before it becomes cloud. But a thermometer plunged into even this invisible part of the current will never mark a higher degree than in the water, rarely so high; and never in any case higher than 212° in the open atmosphere. Hotter than this, no steam can be made without forcible confinement, and then the water also is made equally hot, a thermometer placed in a high-pressure boiler marking exactly the same degree whether in the water or the steam. And in the jet issuing from such a boiler, it will never even rise to 212°, as in that from a tea-kettle, however hot the steam immediately within may be; for so universally is all *visible* cloud colder than this, that the jet from such a boiler, which, unlike that from a tea-kettle, becomes visible *immediately* on passing the aperture, will not scald a hand however close it may be held; which has given rise to the absurd paradox that "high-pressure steam will not scald;" whereas high-pressure steam has never been touched, nor can be, unless by making the hand a valve to help confine it; for when it has issued from a jet, it has ceased to be high-pressure steam.

Notwithstanding all this it has been usual, from the time even of Hero, the Alexandrian writer on Pneumatics, 2,000 years ago, to speak of water being converted into steam by the addition of heat, or, as he expressed it, "converted into an air by fire," the four popular "elements" having then been understood as simply the names of four states of matter, solid, liquid, gaseous, and imponderable, in strict accordance with our latest science. It was impossible to overlook this absorption, or expenditure of fire or heat, in converting water into an air; a portion of both constituents, the water and the heating power or principle, being evidently *lost* as such, or ceasing to show their characteristic qualities, in uniting to form the new substance. Yet it was not until about the middle of the last century that one of our great thinkers, Dr. Black, began to reason precisely on so common a matter, and to deduce from it some highly important natural laws. [See HEAT.] He proved that this disappearance or apparent loss of heat took place whenever a solid melts, as well as when a liquid evaporates; and on the contrary, a precisely equal apparent production or restoration of heat when the same liquid solidifies or the same vapour liquefies. For instance, if a quantity of ice, some degrees colder than freezing, say at 20°, be placed in ever so warm a situation, even in a vessel over a fire, although its temperature will rise to 32° just as quickly as an equivalent mass of any other body (*i. e.* a mass having the same heat-capacity) would rise 12°, yet its temperature will then remain at 32° during the whole time occupied in melting, which of course will be proportioned to the quantity melted; and not until the whole has become water will a thermometer in it again begin to rise as before. During all this time heat enters the ice, and yet neither that nor the ice-water, nor anything that we can observe, becomes hotter. We see that heating power is expended just as if the contents of the vessel were being *warmed*, and yet they are not warmed, but only *melted*. A change is effected, more and more of the solid becomes liquid, and we see that a supply of heat is necessary to effect this, but when all is over we have no more apparent heat, nothing *hotter*, only a vessel of *water* at 32° instead of *ice* at 32°. Dr. Black showed, and it is perfectly established and demonstrable in a variety of ways, that to melt ice simply without any rise of temperature, it must always thus receive and absorb, or render *latent*, a certain precise amount of the heating power or principle, viz. about as much as would heat an equal weight already melted no less than 140°. So also, in the melting of all other solids, there is a fixed quantity of heat, different for each, and generally greater than this, rendered latent; and in the conversion of liquids into vapour, a generally greater quantity still; which in the case of steam is greater than in any other case known, being little, if at all less than would have heated the water, if it could remain water, 1,000°,—(or ten times as much water, 100°; or a thousand times as much, 1°). The various modes of determining this number are exactly analogous to those by which the 140° absorbed in the liquefaction of ice are ascertained. Thus, as the vessel in which ice is melting, so also that in which water is boiling, can be made no hotter by any heat we may apply, until the whole has boiled away. The only effect of a fierce fire is to melt the ice more quickly, or to evaporate the water with greater rapidity, but not to render either hotter. Now Dr. Black, by contriving to keep a plate of iron at a constantly equable red-heat, and placing on it a small tin dish of water, compared the time occupied in heating it from 50° to 212°, which was 4 minutes, with the time afterwards required to boil it all away. This, however, is the least accurate method of any, and gave only an approximation to the relative quantities of heat expended. A better method is that called the method

of mixtures. In melting ice by water, it will be found that if the weights of water and ice be equal, the resulting water is 70° colder than the mean of their temperature before mixing. Thus, no ice can be melted by *its own weight* of water of a lower temperature than 172°, or as many degrees above 172° as the ice is below 32°; and in this case the resulting water will be only just above freezing. It will be the same when ice is melted by 10 times its weight of water 14° warmer than itself; or 5 times its weight 28° warmer; or 28 times its weight 5° warmer; these being the *smallest* quantities that can melt it in those cases. So in condensing steam by passing it through water, one of Watt's first experiments, he was astonished, till Dr. Black explained to him his theory, at the large quantity of water that a little steam could raise to nearly its own temperature. That steam at 212°, may become water at 212°, it must give out heat enough to raise, according to Rumford, 10 times its own weight of water 102°, or produce an equivalent effect, such as heating 102 times its weight 10°, or 1,020 times its weight 1°; and though this is the highest measurement, the lowest, that of Southern, makes the number 942. Another mode of proof by Watt is very remarkable. We have seen that, under forced confinement, water may be heated much above 212° without boiling, that is to say, any boiling will cease as soon as the confined steam acquires the density of saturated steam for the particular temperature maintained. Papin, who, about the year 1700, invented the safety-valve, [see DIGESTER,] applied it chiefly to a small culinary vessel for the highly useful purpose of extracting nourishment from bones, &c. by water of higher temperatures than boiling, and it is called after him Papin's digester. Now, however hot the water in one of these may be made, it is found that, on opening the valve, only a part of the water rushes out in steam, (instantly becoming a dense and *cold* cloud,) and what remains as water instantly cools to 212°. The hotter the original temperature, the greater portion indeed rushes out, but nothing remains hotter than 212°. Moreover, if the whole were previously 95° above boiling, just a tenth of it will thus rush out, so that this tenth, in changing from water at 307° to steam at 212°, takes nevertheless as much additional heat as raised all the other 9 parts 95°; or in simple conversion into steam it absorbs as much as raised all 10 parts 95°. If all were heated at first 190° above boiling, then the portion flying out will be $\frac{1}{5}$th, so that it requires for vaporization, independently of all change of temperature, 5 times the heat that would raise it 190° without evaporation. And in every case the same rule will apply, the part evaporated bearing that ratio to the whole, which the degrees it was raised above boiling bear to 950°.

Important as this quantity, called the *latent heat of steam*, and all laws relating to it, must evidently be to the economy of the steam-engine, affecting fundamentally all questions as to the best form of engine or mode of working, it cannot be said to be either more precisely known, or the least better understood, as to its laws now, than in the time of Dr. Black. Two rules leading, if followed out, to the most opposite results, have, until very lately, if they do not still, appeared in the same books, or almost the same pages, without a remark on their incompatibility, and are alternately and indifferently taken for granted in the same calculations. The first, which is attributed to Watt, and seems, at one time at least, to have been accepted by Dalton, is to the effect that the higher the temperature, the smaller, *by just so many degrees*, is the difference of latent heat between steam and water at that temperature. The other rule, founded on three experiments by Southern on steam of $\frac{1}{2}$, 1, and 2 atmospheres, or 180°, 212°, and 250$\frac{1}{2}$° only, assumes this difference to be constantly equal at all temperatures, being always such as would raise water 942° or 950°, for to this extent did even those three experiments vary.

The former, or Watt's rule, is commonly expressed by saying that the *total* heat of saturated steam (*i.e.* the latent and apparent heat together) is a constant quantity, viz. in round numbers 1,200° on Fahrenheit's scale, so that when the temperature or apparent heat is 212°, the latent will be 988°,—when the former is 250°, the latter is 950°, &c. In Southern's rule the *latent* instead of the *total* heat is constant. But as the quantities are expressed in degrees that, as we have seen, measure no causal force, only an effect whose laws are unknown, it is not at all likely that either these or any other modes of reckoning founded on our present thermometric scale, will agree with the phenomena. Some experiments of Regnault, made by the direction of the French government, have rendered it certain that the truth lies *between* these two hypotheses, or that saturated steam contains *more* heat the hotter it may be, but *less* latent heat. The rule he has deduced, however, as agreeing best with his experiments, is very arbitrary, and unlike the simplicity of a natural law. It amounts to this, that for every increase in the density of saturated steam, there must be an increase of the total heat equivalent to 30·5 per cent. of the rise of temperature; or, in other words, the difference between the heat latent in the steam and in the water, is neither constant, as Southern supposed, nor does it diminish as much as the temperature increases, as Watt supposed, but about 7-tenths as much, viz. 69·5 per cent. Thus the truth would lie nearer to Watt's supposition than to Southern's, as 7 to 3 nearly. The latent heat, in saturated steam of the following different temperatures, will be, according to the three hypotheses, as follows:—

Temperature.	Elasticity.	WATT.		REGNAULT.		SOUTHERN.	
		Latent Heat.	Total Heat.	Latent Heat	Total Heat.	Latent Heat.	Total Heat.
deg.		deg.	deg.	deg.	deg.	deg.	deg.
180	$\frac{1}{2}$ atm.	1020	1200	988·4	1168·4	950	1130
212	1 ,,	988	1200	966·2	1178·2	950	1162
234	1$\frac{1}{2}$,,	966	1200	950·9	1184·9	950	1184
251	2 ,,	949	1200	939	1190	950	1201
276	3 ,,	924	1200	921·7	1197·7	950	1226
294	4 ,,	906	1200	909·2	1203 2	950	1244
321	6 ,,	879	1200	890·3	1211·3	950	1271
360	10 ,,	840	1200	863 3	1223·3	950	1310

What is here called the *total* heat, however, should be called the excess above that of water at 0° Fah. It has been justly observed that the greatest inconvenience of this scale is its not having the zero at that great natural standing point, the congelation of water. In the thermometric systems of the continent, where this is the case, the number in question represents the excess of heat in the steam above that of *freezing water*, which is an actual and well-known standard; whereas, *water at* 0° *Fah.*, which we are obliged to refer to, has never been seen. We might add 140° to the above numbers, and call them the excess of heat above that of *ice* at 0°; or what is much better, diminish them by 32° and call them the excess above freezing water; but this would lead to continual mistakes unless we also reckoned the temperatures from the freezing point.

Again, it is necessary to remember that the latent heat is measured by the number of degrees it would warm an equal weight of *water*, (or rather the number of such weights of water that it would warm 1°,) and that its effect on any other body, or even on the same body in the state of steam or of ice, would be quite different. From observations of the warming and cooling effects of different substances on each other at different temperatures, as well as from the different expenditures of fuel to heat them equally, it is clearly proved that the same quantity of heat which warms a pound of water 1°, will warm a pound of most other bodies much more than 1°, and a pound of mercury no less that 30°, or at least 30 pounds of it 1°. A pound of water and 30 pounds of mercury are therefore *equivalents* in regard to heat. Both have the same heating or cooling effect on the same body, when their temperatures are equal, and this is commonly expressed by saying they have the same *capacity* for heat. But if so, a pound of water must plainly have 30 times the capacity of a pound of mercury, and must (when their temperatures are equal) contain 30 times as much of that heat which is employed in maintaining their temperature, leaving latent heat out of the question. For when an addition of heat is so shared between these two bodies as to have no tendency to leave one and enter the other, the water will have 30 times more of it than the mercury, though both will warm a thermometer equally, or have the same effect on any body touching them, in short the same temperature. Hence, if we call the capacity of any quantity of water 1 or 1,000, that of an equal weight of any other substance is called the *specific heat* of that substance, and is, for almost all known solids and liquids, considerably less than this unit of comparison. If these specific heats were expressed by the numbers representing the capacity of equal *bulks* of the different bodies, instead of equal weights, they would be much less widely unequal, though the numbers would still be less for almost all other bodies than for water. Again, when a given weight of any substance is expanded into a larger space, whether by heat or any other cause, its capacity is increased, so that the specific heat of the same substance is greater or less according as it is rarefied or condensed. Ice and water are an exception to this rule, but an instance of a more general one, viz. that the same substance has always a greater capacity or specific heat when in the liquid than the solid state, and it is generally supposed to have a greater still in a gaseous state. In expressing, therefore, the quantities of heat that disappear, or that seem produced in any process, it is necessary to say on what substance their effect is reckoned. This is generally water, and from it we can of course estimate the number of degrees change (usually greater) that would be produced in any other body whose specific heat is known.

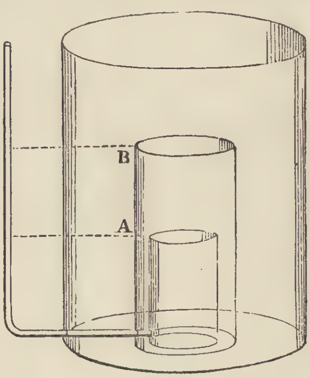


Fig. 2035.

Dr. Dalton contrived the following elegant mechanical illustration, or rather way of better conceiving these changes and their curious effects in liquefaction and vaporization. Let there be three concentric cylinders with open tops, of unequal diameters and heights, placed one within another, and the outer rising higher than the second, and the second than the innermost; and let a slender tube proceed from the bottom of the innermost, through the sides of the others, and turn up vertically as high as the outer vessel, to serve as a gauge of the height a fluid may attain within them. Now if water be poured into the inner vessel, its rise will be accurately indicated by this gauge, till it arrives at the level of the inner vessel's top, and begins to overflow into the next larger vessel. No addition will now be at all indicated by the gauge, till the space surrounding the inner vessel has been filled up to the same level. *Then*, indeed, the gauge will again begin to show the rise of liquid, but will rise more slowly than before, if the supply continue uniform, because the area of the second vessel is larger than that of the first. This represents the thermometer indicating the addition of heat to ice till it arrives at 32°, then remaining stationary till all is melted, and again rising more slowly in the water, for an equal supply of heat, because its heat-capacity is greater than that of ice. So when the liquid arrives at the top of the middle vessel and again begins to overflow, the level will remain stationary a longer time, because a larger space has to be filled up than before, and we may make this space exceed the former in the ratio of 7·6 to 1, (in which ratio the heat absorbed or rendered latent in boiling water into steam, exceeds that in melting ice into water,) and at the same time make the horizontal sections of the three vessels as the numbers 900, 1,000, and 1,550, the relative capacities of ice, water, and steam; and again make the space around the

inner vessel bear to that above its top between the levels A and B, the ratio of 140° to 180°, that of the heat absorbed in liquefaction to that employed in raising water from freezing to boiling; and all the phenomena will be proportionably represented.

As all uniform bodies yet tried, undergo a change of capacity by change of bulk, a *sudden* compression or rarefaction alters momentarily their temperature; which is immediately restored by the communication of heat to or from surrounding bodies. Thus air very quickly compressed into a tenth of its bulk or less, by a blow on the piston of a small syringe, is well known to ignite a bit of German tinder; and on the other hand, if suddenly allowed to expand into twice its former bulk, it becomes for the moment as cold as the air at that height in the atmosphere where it is only half as dense as at the place of the experiment. But in thus becoming colder, it loses no heat or caloric. It is colder only because that same amount of caloric which maintained it at the common temperature when in the smaller space, cannot do so when spread through a larger space. More heat therefore enters it to restore the equilibrium, and this seems to be so much heat lost or rendered latent; but it is again given out if the air be again compressed to its former bulk.

Now there is no doubt that similar effects would attend the compression and rarefaction of steam; and the common or Watt's hypothesis respecting the variation of its latent heat is founded on this, and on a supposition of Watt's, which rests on no experiment, and seems to admit of no direct trial, viz. that if an enclosed mass of saturated steam were thus enlarged or compressed, to any extent, in a vessel *impervious to heat*, its own heat, without addition or diminution, would always just maintain it in the state of saturation. Thus compression, which in all attainable circumstances of the experiment, causes some of the steam to liquefy, would not, as Watt supposed, do so if no heat left the vessel, but would raise its temperature exactly to the point at which steam can support this increased pressure. And an enlargement of space would, as he supposed, reduce its temperature to the lowest at which steam of this reduced density can exist. When, indeed, high-pressure steam escapes into the open air, it is partly condensed into cloud, because, besides the reduction of temperature by expansion, it also imparts heat to the air.

It will be seen that on Regnault's hypothesis, and still more on Southern's, a mass of saturated steam cannot by compression raise its own temperature high enough to prevent the liquefaction of a part. On the other hand, when allowed to expand, its temperature does not, according to them, sink to the lowest that will support it in the enlarged space, but it becomes dry or subsaturated steam, unless robbed of some heat by surrounding bodies, and might even impart some to them without becoming saturated or cooled to its dew-point. Thus in escaping into air perfectly dry or having less than a certain assignable degree of moisture and of density, it might disperse invisibly and form no cloud; which is a thing that could never happen on Watt's supposition if any air, or any fluid besides steam and colder than the escaping steam, were present. Thus if such an escape without forming cloud were ever observed to take place into cold air, even artificially dried and rarefied, it would disprove the common theory. But it is very difficult to meet with any phenomenon not almost equally consistent with any of the three. No conclusion can be drawn from the haze seen in a receiver from which the air is suddenly pumped out, because we know nothing as yet of the relative absorptions of heat in equal expansions of different aeriform bodies, which absorption may be much greater by air than by steam, so as to reduce the steam mixed in it to a much colder temperature than it would reach if expanding by itself.

On the whole it seems that this most important question, What rule connects the temperatures or elasticities or volumes of steam (one or all) with the expenditures of heat in producing it,—a question affecting even the resources of nations, remains to be settled; and it has been truly said that the imperfect knowledge of it must still occasion the waste of more thousands yearly than it would cost pounds to set it at rest for ever, by a series of the most elaborate experiments, conducted on the most extensive scale. To this end, however, a new thermometric scale, graduated to equal increments of heat, and not of expansion, seems one indispensable requisite, even before all else; and more exact determinations of the specific heats of steam and air, compared to water, are loudly called for, the discrepancies between the numbers obtained for these by Crawfurd, Delaroche and Berard, the authorities commonly followed, being such as to destroy all confidence in calculations founded on either. The law of the changes of capacity by changes of bulk, in aeriform bodies generally, is also so mixed up in the question, that perhaps no settlement of it can be looked for till that law be clearly understood, which would require far more experiments than have yet been made on that subject.

STEAM-ENGINE. The term *steam-engine* may be applied to any contrivance for using, as a source of continued motion, the force with which water expands into steam; and a steam-engine is the only means hitherto found, or at all likely to be found, for enabling human labour to obtain from inanimate and naturally motionless bodies, more force or motive effect than that labour could produce directly; or, in the words of its inventor, the Marquis of Worcester, "to make one pound weight to raise an hundred [or any greater weight than itself] as high as one pound falleth."

Mere machinery, or levers, wheels, and the other modifiers of motion known as the *mechanical powers*, [see STATICS,] however combined, being only the means of concentrating or diffusing motion, or converting a great motion of a small quantity of matter into a small motion of a larger quantity of matter, and *vice versâ*, evidently cannot effect any such increase; and were never by competent observers expected to do so, inasmuch as such a production of motion without an

equivalent expenditure, either of motion itself, or of the property of some body to generate it, would in fact amount to a *creation* of motion, which must be as impossible to any creature as the creation of matter. In order to obtain more motive effect than can be produced by his own muscles, man's most obvious, and therefore earliest expedient, is the domesticating of animals, and the contrivance of such machines as the carriage and the cattle-mill, by which to utilize the muscular power of such animals. His next, and probably his true and ultimately universal resource, is to the perpetual motions of nature, *i.e.* to those effects in which either the earth's rotation, or the motion of heat from the sun into space, is so resisted as to have brought together, or concentrated in one spot, such a portion of their effect, as man may wholly or partly divert to his own use. Thus, in a stream, nature has, by the configuration of the valley, brought together an assignable portion of the sun's motive effect in raising vapour from the whole globe, and concentrated it locally in one line, or even an assignable part of it in one spot, that of a waterfall, which is the easiest and first natural mover to be utilized, by the overshot wheel. In flat countries, nature, not having produced such a concentration of power, man has to do it, and he effects his purpose by means of mill-ponds and the *undershot wheel*, which is evidently a more artificial contrivance than the *overshot*. *Tide-mills*, driven by the tides flowing into and out of an excavated reservoir, are a still further refinement, made, it is said, by the Romans, but hardly developed even in our own days. Here the motion used is a portion of the earth's rotation, so resisted by the moon holding back the waters from wholly following it, that some motion is continually lost by their friction upon every shore. Indeed, this friction must actually retard the rotation from age to age, and may, possibly, by compensating that acceleration which astronomers show must accompany the contraction of the globe by loss of internal heat, account for the known invariable length of the day since the time of Hipparchus. Thus, although we are accustomed to look on the planetary motions in free space as being effected without friction, this is not the case with our earth; and so true is it that motion, like matter, can only be transferred by us and not created, that the motion which we derive, even from the sun or the earth, is just so much motion lost to them; although equally lost whether we apply it or no. Whether it grinds our corn, or "on the unnumbered idle pebbles chafes," it is so much of the earth's original impulse absorbed, as that of a machine is absorbed in chafing on its axle.

Windmills are a great advance on watermills, since they are not restricted as to locality, and thus are more artificial, inasmuch as nature has not concentrated the motive effect in one place, except in the case of the ridge of a hill which intercepts twice as many winds as its side. The original motion here, as in the stream-mill, is that of heat from the sun into remote space. But it is resisted by, and acts by the expansion of, *air* instead of *water*. Thus every stream-mill is a sun-heated steam-engine, and every windmill a sun-heated air-engine. Of all the natural utilizable motions, winds are the greatest in amount, and probably their application is as yet in its infancy, as well as different in method, from what will ultimately prevail. By far the larger portion of the total wind-power, or that exerted on the watery surface, is spent not so much in friction as in raising waves, which, growing throughout their whole course, do in fact store up all this power (as that of a windmill might be stored up for future use by pumping water into a reservoir), and give it out only on breaking upon an obstacle; so that, on the coast lines, all that wind-power not available on the land (except what is destroyed in encounters of opposite waves) is concentrated for man's use, as soon as he can solve the problem of obtaining equable motion from a motion so extremely irregular.[1] If waves only lift each particle of water on the average 1 foot once in 10 seconds, this would exceed nearly 100 times the utmost local effect of tides, viz. 45 feet once in 12 hours; which will show how greatly this source of power exceeds that of tides, which is the next in amount. The total stream-power (which might be reckoned from the yearly evaporation, and the height of the centre of gravity of the surface on which rain falls) would be utterly insignificant compared with even the tide-power.

But the main source of artificial motion may yet be that of heat from the earth's interior, through deep borings. Meanwhile, however, there has been inducement, in most civilized countries, to carry out the Marquis of Worcester's fine anticipation, (indeed *invention*, for he is now known to have constructed and used the first steam-engine,) by utilizing the motive power stored up as it were in a latent form, in those materials that have been placed within our reach uncombined, and yet having such chemical affinities as to combine *with force*, when once placed in circumstances that begin their combination. Properly speaking, there is only one such source of power, the oxygen of the air. The great majority of natural bodies are combined with as much oxygen as they can hold, and such we call *incombustible;* and so far from containing any latent power to be thus used, they absorb or require the application of much power, or of heat, which is equivalent, before they can be deprived of this oxygen. But when this is separated, the remaining substance will tend to regain it, and under favourable circumstances will regain it from the air

(1) What is wanted here is something analogous to Worcester's "semi-omnipotent engine," which has been unaccountably confounded with his steam-engine, although distinctly numbered by the ingenious Marquis as another one of his "century," and bearing no analogy of purpose, or possible application to it;—"an engine so contrived, that working the *primum mobile* forward and backward, upward or downward, circularly or cornerwise, to and fro, straight upright or downright, yet the intended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping the other, but, unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore I call this a *semi-omnipotent engine*, and do intend that a model thereof be buried with me." It was buried indeed, and, if re-invented, will soon bury the steam-engine.

with as much force as was necessary before to separate it. If, therefore, nature produce any bodies in such a state, viz. either void of oxygen, or with less oxygen than they have attraction for, we have in them, as in domesticated animals, a store, as it were, of latent motion or activity, since they will continue of themselves an action which we only begin or set going. But of course a certain quantity of them will only give a certain amount of action, in absorbing the fixed amount of oxygen with which it can combine, so that the power is obtained at the expense of the material, since it is, when combined with oxygen, spent or consumed so far as regards this property of yielding motive power.

Such bodies there are, both mineral and vegetable, and we call them *combustibles*, and the action of their union with oxygen, *combustion*. But it must be observed that all combustibles do not necessarily continue this action when once begun: the continuance of this action depends on whether they tend to combine with more force or with less force than is necessary to maintain the circumstances in which alone they combine at all. The chief of these circumstances is commonly a certain high temperature, and if the action produce not heat enough to maintain this, it evidently cannot continue of itself; and the body, although combustible, and contributing to the heat of a fire in which it is burning, cannot be *set* on fire, *i.e.* made a fire of alone. Such is *iron*. But most combustibles produce in burning far more heat than is required to light them; or, what is equivalent, they continue the action once begun, not only with force, but with much *spare* force for other actions. Such we call *fuels*, and they have been burnt in all ages for the sake of the mere heat yielded, without any intention of utilizing the *motion* by which that heat is diffused and the temporary disturbance of heat-equilibrium restored; for, indeed, it was impossible from the appearances about a fire, to conjecture the enormous amount of this motion. Even the fact of a large vessel full of water disappearing by this means does not necessarily lead us to consider the great height to which all that weight of water has been raised; and when the same power is expended on the viewless air, whose weight is made sensible to us by no common phenomenon, we have no means of guessing how great a quantity must be moved, and how far, before the heat evolved from the fuel can be reduced to equal distribution in the atmosphere. So little, therefore, does this motive effect strike most observers, that the first applications of it, as we learn from Hero, who wrote about 120 B.C., were for the purposes of magic or priestly imposture.

In his "Pneumatics" are explained several pseudo-miracles, probably performed by the Egyptian priests of his time, in which sounds or motions of tangible objects are made to ensue on the lighting of an altar, the motion being effected through the medium either of hot air or steam; and in one of them, steam generated in a vessel concealed within the altar, was conducted through the bodies of two statues standing beside it, and made to press on some wine so as to raise it in a pipe, and make it flow out of two phials held in their hands; conveying the idea to the uninformed multitude that these "dumb idols" assisted in the libations.

On the revival of learning, many Italians made or described toys on the same principle; such as "fire-wheels," "æolipiles," &c., which were regarded much in the same light as those in which motions are now produced by electricity or electro-magnetism, and probably moved with as little force.

The recognition of the enormous magnitude of the power so evolved from fuel, the idea of concentrating for use a great part of it by means of confined steam, and of substituting it for muscular labour, are, therefore, exclusively modern, and originated in the unfortunate nobleman above named, and, singularly enough, in the same country—England—that has since originated every improvement thereof, and carried the principle to its utmost application. It is singular, because England was not, in Worcester's time, the home either of science or its application, nor did it contain one philosopher capable of appreciating in the least his wide and far-sighted views. There is actually no record in the English language of the existence of his engine; and but for the diary of Cosmo de Medici's visit to this country, we should still be ignorant of the fact that water had, previous to that period, been pumped by steam, out of the Thames, at Vauxhall, or that Worcester had ever been more than the prophet of the steam-engine. After extreme reverses he wrote, in confinement in the Tower, his now famous "Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected," and he died in 1656, before physical science was imported by Wren, Hooke, and Newton, or could be said to exist in England. His anticipations are remarkable for their strict limitation to the truly valuable and beneficial uses of fuel-power, "not only with little charge to drain all sorts of mines, and furnish cities with water though never so high-seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions, but likewise supply rivers with sufficient to maintain and make them portable from town to town, and for the bettering of lands all the way it runs, with many more advantageous and yet greater effects, of profits, admiration, and consequence,—so that deservedly I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions."

We have then since the time of this great invention, *three* sources of motion, which have been substituted for human muscles. The present knowledge of natural laws does not permit of the conception of a larger number:—

1. Animals.
2. Perpetual motions.
3. The burning of fuels.

The means of thus applying the last source was not, by its inventor, nor generally in the last century,

called the *steam-engine*, but more properly the *fire-engine*. If this name had been retained, we should not have had to encounter the absurd questions about "superseding steam." Steam is not the agent, but only the medium or instrument through or by which it acts, as our will acts by means of muscles which it has the power of contracting. All that is required in this medium is materiality and the property of filling more or less space by the action of the fuel upon it. Steam, or rather water, is selected simply from its abundance, and we might as well talk of superseding earth for embankments, or water for filling canals, as of superseding water and its vapour for filling fuel-engines, unless it could be proved that the only other costless material, *air*, expands with more force for the same accession of heat. Enough has not been settled as to the specific heats of these bodies to decide this point; but in all probability the same fuel will produce the same motive effect altogether, whatever the matter it act upon by way of expansion, whether air, steam, water, or even iron. But although the expenditure of *heat* or *fuel* for a given effect would most likely be exactly equal with each medium, the quantity of medium required to absorb and carry that heat would differ enormously, as well as the relation of the velocity to the load moved. With a solid or even liquid medium, the motion would be through so small an amount of space, that it must be immensely enlarged by transmission from short lever arms to long ones, or from axles to the rims of wheels, and must require excessive strength in the first parts, together with extreme nicety of fit. With air, on the contrary, the smallness of its difference of pressure with any practicable difference of heat, would require that it should act on vast surfaces or pistons, and through a great space, making the vessels in which it worked unwieldy. But a liquid expanding into an air has immense advantages over a body retaining either state unchanged. The change of state always involves a change of bulk far greater than the same change of temperature would produce on a body retaining even the aeriform or most expansible state. It seems indeed proportional not to the change of *sensible* but of *total* heat, most of which, we have seen, becomes *latent* in the aeriform body. [See STEAM.] Furthermore this absorption of heat is itself most advantageous in other ways. It greatly diminishes the difficulty of retaining the heat where it is wanted, since only the *sensible* and not the *latent* heat tends to spread and equalize itself. It keeps the whole machine cooler than it must otherwise be, by the whole amount rendered latent, which in steam we have seen to be near 1,000°, or enough if sensible to produce a *red* heat. Lastly, it leads to a most useful phenomenon, that could never happen with a body retaining one constant state, such as air. Air ever so hot and ever so cold, mixed together, would occupy nearly or quite the same bulk as before the mixture; but steam coming in contact with such a quantity of water, colder than itself, that the total heat of both is insufficient to keep *both* vaporous, is suddenly condensed, and the whole becoming water, occupies some hundreds of times less space than when the steam and water were separate, although their total heat remains the same, which is the reason why the change may be made so sudden, no time being required for transfer of heat to or from surrounding bodies.

Again, all these advantages will evidently be greater, the more heat the liquid absorbs in evaporating, and the more it expands in doing so. Now it is very remarkable that water greatly excels, in both these respects, every other known body, even among artificial chemicals. It absorbs, as we have seen, nearly 1,000° of heat: there is scarcely any other liquid that absorbs half so much; moreover, water as steam of atmospheric pressure, occupies 1,700 times its liquid bulk; whereas, no other liquid is known to expand one-third so much. It may therefore be a providential appointment that has made water the most abundant substance on the surface of our planet, one so peculiarly adapted to these mechanical purposes, that in the whole range of our present knowledge, we know of none other approaching it in fitness for such applications.

These are strong reasons for supposing that steam and water must always supersede air, and of course all costlier materials, as the media for carrying the power of caloric or fire; and consequently that the steam-engine will continue to exclude all other kinds of fire or fuel-engines, and yield only, as it undoubtedly must, to such changes in the condition of mankind, and the distribution of their property, as may revive the former less centralized use of the perpetual motions, by stream, wind, tide, and especially *wave*-mills, or of central heat; and leave the fuel, recent or fossil, to its more obvious destinations of warming buildings, cooking, and other chemical operations.

Worcester's original *steam-fountain*, as it would now be called, so far as the accounts of it give materials for restoration, appears to have been something like Fig. 2036. The water to be raised was placed in the boiler B, so as to supply the steam, the pressure of which drove it up to D; and when B was emptied, the cock F was shut, and the steam generated in another vessel C, to raise its contents, while B was being refilled. Worcester speaks of so making his vessels that they were strengthened by the pressure from within, *i.e.* their seams tightened, as they would be if made with internal flanges; and he burst a piece of ordnance in his preliminary experiments on their strength. He concluded that the pressure of the steam was limited only by his power to confine it, and that however high the lift from B to D, steam might, provided the vessels were only strong enough to contain it, be made sufficiently elastic to press the water from B or C up the ascending tube into the reservoir D. He found that one measure of water was required to be evaporated in B, to drive up 40 measures of cold water, he does not say how high. Were there no loss, it would be capable, as we have seen, of driving up 1,700 to the height of the water-

column that balances the atmosphere, or 33 feet. The waste was occasioned by the fire spent in heating not

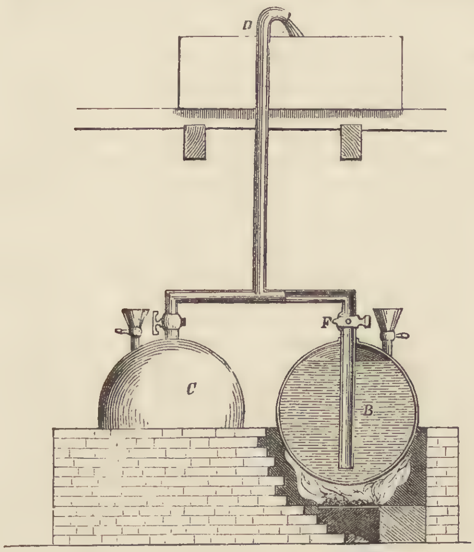


Fig. 2036. WORCESTER'S STEAM-FOUNTAIN.

only the steam, but the whole of the raised water to boiling, and it must have been enormous.

The Marquis of Worcester's small book attracted some attention on the part of mechanicians, even in the generation of its author. About twenty years after the death of the author, Sir William Morland constructed the second steam machinery, with what improvements on the first we know not. He endeavoured to draw the attention of the French monarch to the subject, but does not appear to have met with encouragement.

About the year 1695, attempts were made in France by a native, Dr. Papin, the inventor of the *safety-valve*, (without which the steam-engine could not exist,) and consequently of the hardly less important *digester*, which bears his name. [See DIGESTER.] Papin's first attempts were with one vessel only, but he soon found the advantage of separating the steam-generating vessel, henceforth called the *boiler*, from that containing the water to be raised. This did not, however, obviate the heating of the latter, which condensed most of the steam admitted to it, and was raised nearly to the boiling point. In order to avoid so much loss from this he afterwards, about 1700, invented the arrangement shown in section, Fig. 2037. The safety-valve here appears on the boiler B, and is, as every one knows, a small cover or stopper, sitting loosely on or in a small aperture, but kept down by a certain weight, which is here, as usual, made to increase its effect by a lever, so that it may, by being slid along it, like the weight on a steel-yard, serve without change of weights to vary the pressure which the steam is allowed to acquire. This, of course, it cannot exceed without lifting the valve and escaping, until reduced below the limit thus allowed it. The valve is simply the weakest or most yielding part of the boiler, and by taking care that it shall always be the weakest, the danger of explosion is avoided. Papin's next improvement was a thick or hollow float P, lying on the water in the vessel C, and fitting its sides as closely

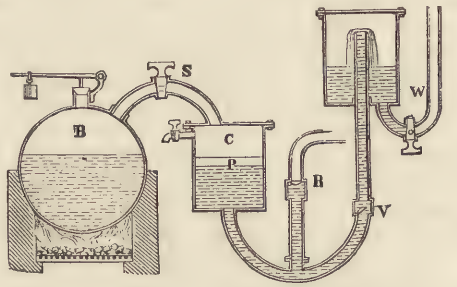


Fig. 2037. PAPIN'S STEAM-PUMP OR ENGINE.

as possible, to prevent the contact of the steam with the cold water, which he had found wasted so much, although here too a great deal of steam would be condensed by transferring its heat through the float. His water-pipe first descended, then ascended, and had a valve opening upwards only, as at V, while a pipe R, bringing the supply from a tank to the lowest part of the main pipe, had a valve opening downwards towards the main pipe. The object was, that when the contents of C had all been driven up through V, it might be refilled by shutting off the supply of steam at S, and what was thus enclosed in C being rapidly condensed into water, an almost entire vacuum would be left between P and S, so that the atmospheric pressure on the supply tank would drive water through the valve R and up to fill C, even though it were some feet higher than the original level of the water. The cock S was then opened, and a new supply of steam admitted into C, the effect of which was to depress the float, and the water under it, which can only find exit through the valve V, and not through R, which opens towards it; and when much water arising from the condensation of steam was accumulated on P, it was let out by the small cock at the side. The ascending pipe terminated in a close vessel, in order that the air compressed there might press the water up through a second ascending pipe W, with a continuous, instead of an intermitting stream.

It is uncertain whether the idea of lifting a weight by the atmospheric pressure against a vacuum, made by the *condensation* of steam, (a mode of using its power quite distinct from Worcester's,) was original with Papin, or imitated from the machinery of Capt. Savery, who, about the same time, revived the attention to steam power in England. Savery's engine, as shown in section, Fig. 2038, was secured to him by patent in 1698, and was the first to be practically applied for draining mines. The steam is alternately admitted and shut off from the *steam vessel* or *receiver* R, by the cock C. When first admitted, whatever is not condensed in warming it, passes on into the rising pipe, which it cannot descend, because both the valves V V′ open upward, but it lifts and escapes by the upper valve V′, the rattling of which warns the

attendant to stop the steam-cock C, and as all air has been expelled from R, and cannot return through V′, the gradual cooling and condensation of the steam in R leaves a partial vacuum, into which water from the well is driven up through the valve V. When R is

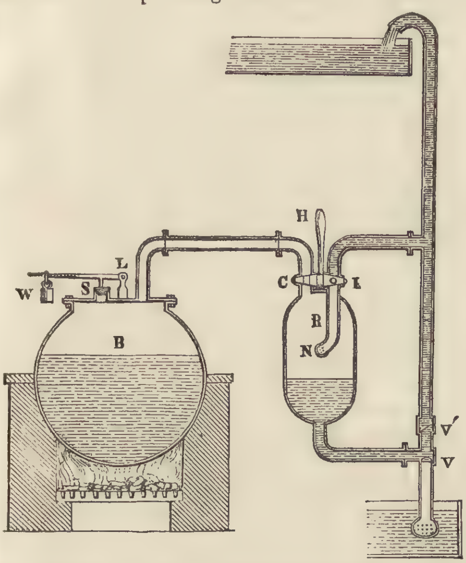


Fig. 2038. SAVERY'S STEAM-PUMP OR ENGINE.

cold, it is nearly full of water, and the steam being again admitted through C, presses this water not back through V, as that valve cannot open downward, but up the rising pipe. When all is expelled, the cock C is again shut, and another called the *injection-cock* I is opened, which admits water from the column that has been raised, (and cannot return through the valve V′,) to enter, and be dispersed through the steam in R, from a nozzle N, pierced with holes in all directions. This shower rapidly condenses all the steam and makes a new vacuum, into which a fresh receiver-full of water from below opens the valve V and ascends, ready to be expelled upwards by another supply of steam. As the two cocks, C and I, are never to be both open, and need never be both shut at once, they are so connected with a single handle H, that one motion does all that is necessary to change the action of the engine, from the sucking up water by the condensation of the steam, to the driving it up by the pressure of the steam, and *vice versâ.*

Papin, who was a most ingenious but unpractical mechanician, described other modes of using steam without the loss entailed by allowing it to touch the water to be raised; and certainly he was the first to propose, although in useless forms, the suspended *piston,* moving up and down in a smooth cylinder exactly fitting it, as in all modern engines. A small quantity of water in the bottom of this cylinder, being vapourized by placing fire underneath, drove up the piston; and on allowing it to cool, and again become water, the atmospheric pressure brought the piston down, with a force sufficient to lift, by a cord and pulleys, a considerable weight. He thus invented two most important parts of our engine, the *safety-valve,* and the *piston.*

Both Savery and Papin proposed to apply their engines to the production of an artificial waterfall for driving mills or other machinery, that is, they would have raised by steam the water of a lower reservoir into a higher one, in order that, by continually flowing back, in a circuit, it might drive an overshot water-wheel, from the rotation of which, the motions for any other mechanical operations are best derived. This, however, was never done, and Savery's engine continued to be employed only in the drainage of some Cornish and Devonshire mines, until it was superseded in 1705 by a most happy combination of the ideas of Savery and Papin: this was the *atmospheric engine,* invented by Newcomen, a smith of Dartmouth, and patented jointly by Newcomen, another person, and Savery himself. The atmospheric steam-engine is in fact no more than the practical and useful form of Papin's last-named proposal for raising a weight by the atmosphere pressing down a piston first lifted by the formation of steam under it, and then left unsupported in consequence of that steam being condensed again into water; and the main addition necessary to make this of practical use, was simply the *separate boiler,* for want of which Papin, having to generate and condense his steam in the same vessel, lost so much time in the alternate heating and cooling, that the whole was merely a curious experiment; and it is wonderful that so ingenious a man, knowing that the idea of separating the boiler from the working cylinder had already been developed by Savery, did not see the necessity of such separation in order to confer any practical value on his invention. No sooner was this done by Newcomen than the steam-engine at once took the general form and properties which it has retained to this day, insomuch that there is not a change introduced by him which has not been permanent, nor a single part or feature of Newcomen's engine but continues an essential in all future engines, merely improved in detail, but identical in name and principle. And this, be it observed, is what cannot be said of any other improver, certainly not of the more celebrated Watt, each of whose amendments was the only successful one out of a numerous batch of patented contrivances, many of them most chimerical, and the majority never heard of again, apparently heaped together like lottery tickets in the mere hope that all might not be blanks.

Newcomen's engine, then, in which most of the parts still essential to be understood, originated and took their present names, is represented in Fig. 2039, cut through the axis of the cylinder C and the piston P. The latter is suspended from one end of the *working-beam* A A, which is balanced at its centre, on the wall of the engine-house, and at its other or *outdoor* end is suspended the rod of the pump, or series of pumps, by which the mine is drained. This, with its appurtenances, is commonly so much heavier than the piston, as to overcome its friction in the cylinder, and thus quickly draw it up to the top, where it remains when the engine is not in action. Should the pump-rods alone be not heavy enough for this, they

are loaded with weights W, the amount of which regulates how quickly the up-stroke of the piston shall be performed. The piston was bound with leather, and kept air-and-steam-tight by a little water lying on it, supplied from the tank T. The cylinder has no cover, but a flat bottom, so that no steam may be wasted by occupying space not necessary to support the piston. Now, when steam is admitted from the boiler B through the steam-cock *c*, it has to drive out the air occupying the cylinder. This it does by the pipe ending in the valve *s*, which resembles a small unloaded safety-valve immersed in water, and is called the *blow-valve*, or *snifting-valve*, from the peculiar noise made when, the air having all bubbled out, the steam begins to follow, and instead of escaping in bubbles, is instantly condensed by the water, with a kind of decrepitation. This sound, then, being a sign that the air of the cylinder is all displaced by steam, the attendant, on hearing it, shuts the cock *c* and opens another by which water from the cold reservoir T was, in Newcomen's first engine, thrown in a shower over the outside of the cylinder, so as to cool its contents, reduce all steam above the cock *c* to water, and therefore to about $\frac{1}{1700}$th of its bulk, and thus leave the piston unsupported against the atmospheric pressure of above 14 lbs. per square inch, which of course quickly brought it to the bottom, lifting, in the rods and weights W, and the water following them, any weight less than 14 times as many pounds as the area of the piston P had square inches. In an early trial, however, a small leak in the piston allowed some of the water lying on it to keep it tight, to fall through into the cylinder when full of steam, and this produced an instantaneous condensation and descent of the piston so much faster than usual, that the experimenters at once altered their cold water pipe, and made it enter the cylinder and throw up a jet within it, (as shown in the figure,) instead of merely

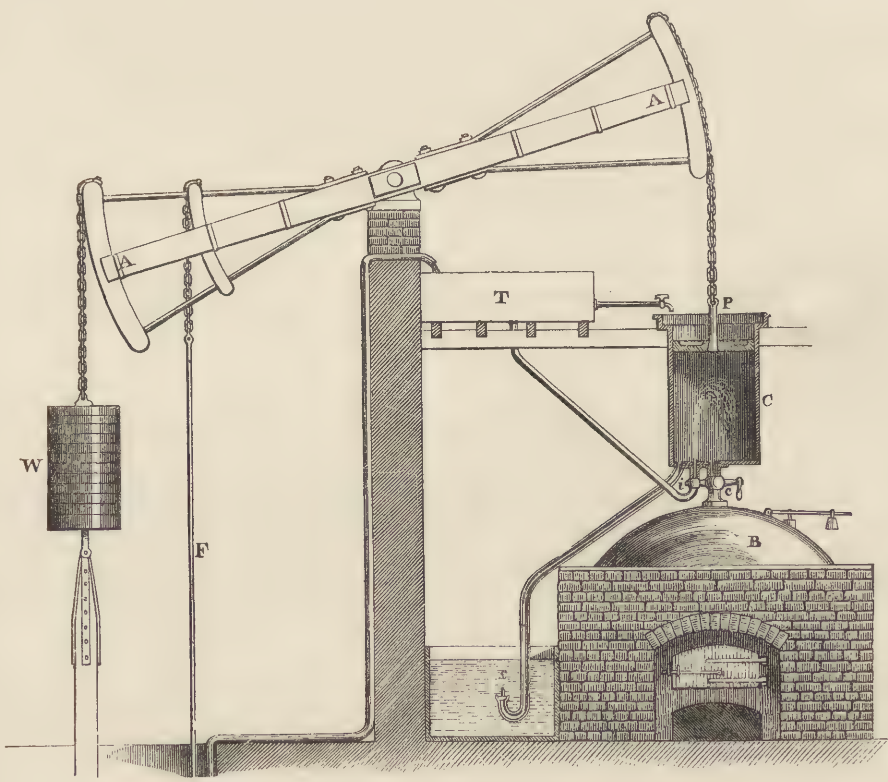


Fig. 2039. NEWCOMEN'S, OR THE ATMOSPHERIC STEAM-ENGINE.

washing its exterior, whence the cock *i* (retained, like all these elementary features, in some shape, to this day) is called the *injection-cock;* and thus did they accidentally discover, and forthwith turn to account, the third of those properties of steam on which its mechanical usefulness depends. Worcester had taken advantage of its *expansive force* only; Savery, of its *ready condensation* by cold, which creates a further force by calling into action the pressure of the atmosphere; but it is doubtful whether both these could have rendered the steam-engine really useful, but for Newcomen's discovery of the *instantaneousness* of this condensation when effected by injection, *i.e.* by the contact of water minutely scattered through, and moving against, or mixed with the steam, as by a shower or jet; for it has been remarked that the steam-engine could hardly exist as a useful power if the destruction or liquefying of a given quantity of steam took a time at all approaching that required for its production.

As the large pumps of the mine rarely lift the water to the surface where the engine stands, but only to some lower level whence it flows off through the adit to the lowest ground in the neighbourhood, a smaller pump, worked by the rod F, served to lift, from the adit level to the tank T, as much water as the engine itself required; all of it being first used for injection; and then, from the hot water that ran out at each stroke by the pipe and valve S, consisting of both the injection-water and condensed steam, a portion equivalent to the latter was returned to feed the boiler; the larger part, however, escaping, and carrying with it all the heat produced by the fire, except what might pass up the chimney, or radiate from the hot surfaces of the furnace, the boiler, and the cylinder.

It will be seen that the analogy with a common hand-pump is so far preserved, that the whole of the work is done by the up stroke of the pump rods, or the descent of the moving power at P; and this being produced by a force acting *within* the engine-house, is called the *in-door* stroke. When this was completed, the attendant closed the cock *i*, and re-opened *c*, and the piston being now as much or nearly as much pressed from below by the steam, as from above by the air, it is free to re-ascend, and is quickly brought back to the top; which motion being due to the weight acting *outside* the engine-house, is hence called the *out-door* stroke, and restores the machinery to its original and resting position, ready for another injection, to produce a second in-door or working-stroke. Thus, although steam be the agent through which the power of the fuel is exerted, yet it is not in the generation, but in the destruction of the steam that its force is here obtained. The filling of the cylinder with steam does no work directly, but stores up its effect for future use, by lifting a dead weight, (viz. the column of air incumbent on the piston,) whose return by gravity afterwards does the work. Although rarely seen in use,[1] there is much reason to think with the Comte Pambour, that with certain additions (chiefly Watt's separate condenser and air-pump, presently to be described) and some contrivance for well clothing and retaining heat in the cylinder, which might possibly be immersed in the boiler, the atmospheric engine might again become useful under certain circumstances, especially in new countries, where the fuel is wood, and its economy less important than that of metals, and of skilled labour. For it is certain that no other form of engine will produce a required power with so little first cost, so little strength and mass in the construction, or so little dependence either on nice workmanship or solid foundations; and although we are accustomed to look on all these as trifles compared with the daily saving of a little fuel, the reverse still holds good over at least half the world. It is even conceivable that the atmospheric engine might, in such countries, reappear in steam navigation; the first essays at which were undoubtedly on this principle, viz. that by our countryman, Jonathan Hulls, in 1736, if not the paradoxically far-sighted, and almost prophetic attempt of Blasco de Garay, who, in 1543, a century before Worcester, and before even the effects of the air's weight were attributed to weight at all, is said to have propelled a vessel in Barcelona harbour, by power evolved from a caldron of boiling water!

A boy named Humphry Potter having to attend one of Newcomen's engines, is said to have relieved himself of the trouble of turning the two cocks *c* and *i*, Fig. 2039, at each stroke, by so connecting them by levers and strings with the moving parts of the engine, as to make it, in finishing each stroke, to shut one and open the other, and thus itself produce the next stroke; and this being observed not only to save attendance, but greatly to add to both the regularity and speed of working, a more refined mechanism for the purpose was forthwith contrived, and was much improved in 1717 by Henry Beighton, F.R.S.; since which time *valve-gear*, or the means by which every stroke of the engine may open and close, at the proper times, all cocks, valves or passages necessary to the stroke, has been deemed indispensable in all engines, and has received greater varieties of form and elaboration of contrivance than any other part of the system.

In 1720 a theorist named Leupold proposed a mode of employing steam power exactly opposite to Newcomen's. Retaining the arrangement of open cylinder and piston suspended from a balance-beam, he nevertheless abandoned the power obtained from the condensation, and returned to Worcester's principle of employing only the excess of the steam's pressure over that of the atmosphere. His boiler, therefore, required great strength, its whole interior having to bear as much pressure per square inch as that which moved the piston; whereas, in Newcomen's engine, by raising the steam to no more than the common boiling point, the boiler might have no tendency either to burst or collapse, and consequently be made only strong enough to support its own weight, and yet the piston be driven by nearly 14 lbs. per square inch. Leupold proposed two cylinders to be placed side by side, (as shown in Fig. 2040,) each working its distinct beam and pump; and while steam was admitted into one cylinder, so as to drive up its piston, the other was allowed to communicate with the open air, so that the cylinder-full of steam admitted to it in the previous stroke might be expelled by the descent of its piston, and so on alternately. Both pistons, therefore, had to preponderate over the weight of their respective pump-rods, and this sufficiently to overcome the friction of the whole apparatus, and bring the pistons to the bottom of their course when out of action, which is just contrary to Newcomen's distribution of weight, and plainly far less fitted to mining purposes, the pump-rods and the water raised by them being usually by far the heaviest side of the balance, and requiring a most cumbrous addition to the steam-piston, if that is to be made to preponderate. Moreover, the transmission of power from the piston to the

(1) In August 1852, the Editor saw a Newcomen engine at work, at a coal and iron pit near Glasgow. See MINE—MINING, page 272.

beam, which in Newcomen's engine is made by a *pull* only, and therefore needs but a chain, (see Fig. 2039,) is here made by a *push*, so as to call for a stiff con-

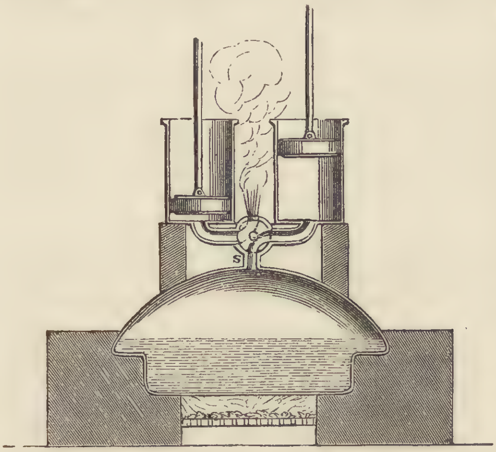


Fig. 2040. LEUPOLD'S PROPOSED STEAM-ENGINE.

nexion called the *piston-rod,* which, although necessary, as we shall see, in most of the modern applications of steam, should not be so in these *single-acting* engines, *i.e.* such as exert their power only in one direction, and would in this case be very liable to bend and break. In short, the defects of Leupold's contrivance are so great that we cannot wonder at its never having been put into practice, although it has always held a place in the history of the steam-engine, as the supposed progenitor of our present *high-pressure*, or *non-condensing* engine, to be described hereafter. But in truth, as what is called the "high-pressure principle," (or that of employing steam against air, instead of against vacuum or weaker steam,) was necessarily the *first* mode of employing it by Worcester, and as all condensing engines are something *more* than this, the mere *omission* of condensation cannot, we apprehend, be called a "principle" or an "invention" at all, any more than the omission of arches in building, or the abandonment of anything else as not worth doing, which had previously been thought worth doing. And if it be said that Leupold's was the first non-condensing engine with pistons &c. interposed between the steam and the water to be raised, these arrangements were merely taken (or rather, badly imitated) from Newcomen; nor is there one feature even original in this proposal, except the *four-way cock s*, by which one movement is made to effect all the changes necessary at the beginning of a new stroke. This cock is a solid cylinder, pierced with two curved passages, as seen in the figure, and turning in a hollow cylinder from which four ways open, to the two cylinders, the boiler, and the open air. By turning it one quarter round, or from one into the other position shown in Fig. 2041, it will be seen that the piston previously receiving steam from the boiler, is left to expel that steam into the air, while the other piston ceases to communicate with the air and begins to receive steam from the boiler. Another quarter turn, in either direction, would restore the former conditions, so that, by either moving the cock alternately through 90°, or making it constantly revolve, the two engines are kept at work. Of course, in this crude form, the grinding of the two cylindrical surfaces, one within the other, would rapidly wear them so as to produce leakage; but as this is easily remedied in two ways, (either by the simple substitution for the solid cylinder, of a hollow and elastic one, slit from end to end, so as to expand and press out against the enclosing case, or by making both parts conical, and constantly pushing the movable cone as far as it will go into the fixed one, by a spring, or weight, or cushion of steam,) there seems no reason why this part of Leupold's engine should not still be found useful as one of the simplest possible varieties of valve-gear.

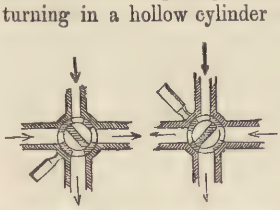


Fig. 2041. LEUPOLD'S FOUR-WAY COCK.

For about 60 years, from 1710 to 1770, the engine remained almost in the state to which Newcomen had brought it, although occupying for the latter part of that time the attention of Smeaton, indisputably the greatest *statical* architect of modern times. It is truly astonishing that a designer so unrivalled in the mechanism of all *fixed* structures, fulfilling in them the newest and boldest requirements in the very simplest ways, (and moreover so ingenious and conclusive an observer and experimenter on the mechanical powers, including steam itself,) should be employed on this engine, and even on extending its scale far beyond any previously attempted, (his largest engine being of 108 horse-power,) without seeing the great improvements for which it was now fully ready, but which were left for Watt to carry into execution. It seems, however, that even between Statics and Dynamics, which are regarded as divisions of the same science, or at least between the inventive application of each, Architecture (or *Engineering* as it has been called since Smeaton's time) and Machinery, the connexion is not close enough for the same persons to excel in both; although it is easily seen that a really good machine must possess excellences of both kinds, and that many most ingenious modern ones by Watt and his successors, are sadly deficient in the statical element, and hence fall as far short of Smeaton's atmospheric engines in economy of material and wear, as they excel in that of fuel and attendance.

Though all Smeaton's improvements were, in comparison with those of Watt, mere matters of detail, they affected nearly every part of the engine, and, not confined to structure and proportions (his true province as a statical engineer), many effected also savings of power, heat, or fuel. He first made experiments on the form of boilers, which had hitherto been mere repetitions of the alchymists' vessels, either globular, or large portions of globes with a flat bottom, and the fire beneath, wasting most of its heat through the surrounding walls, or by passing up the chimney. A little consideration led him to the placing

of the fire within, entirely surrounded by the matter to be heated, and then to the lengthening of the boiler into a horizontal cylinder, through the whole length of which the flue might be carried from the fire at one end to the chimney at the other. This latter improvement, however, had not occurred to him when his largest engines were constructed. They still had what he termed, from its shape, a hay-stack boiler. Of course the more we deviate from a globe, (the figure of greatest capacity with least surface,) the more material we spend to enclose a given bulk of contents, and therefore the worse vessel we make for a storing vessel or reservoir; but this has nothing to do with the efficiency of a boiler, which is measured not by how much it holds, but how much it evaporates in a given time; and as this depends, *ceteris paribus*, on the number of bubbles of steam that can be forming at once, that is, on the area of surface the water rests on, and not at all on the quantity of water, whatever is best for a tank must be worst for a boiler, and *vice versâ*. Smeaton found the best proportions for the length and diameter of the working cylinder in his largest engines, to be as 3 to 2, his great Chasewater engine being 6 feet in diameter and 9 feet in height, a much wider proportion than had previously been used; although Mr. Francis Blake, F.R.S., had proved theoretically that the wider and shorter the cylinder, the better it should be, without limitation unless from circumstances even yet unobserved; for while the pressure urging the piston varies as its area, or the square of its diameter, the friction retarding it varies only as the circumference, which is as the simple diameter. In other words a piston four times as large as another, has only twice its circumference and twice its friction, so that when driven by the same quantities of steam per minute, (which they must be if performing equal numbers of strokes in two cylinders of equal capacity,) the larger piston will do the most work, or overcome the greatest resistance *outside* the cylinder, when both are made, by levers, &c., to move that resistance with the same speed, for the actual speed of the large piston would of course be only a quarter that of the small one. To this day the limits of this principle do not seem to have been reached; for although most cylinders are shorter proportioned than Smeaton's, and even shorter than their diameter, the tendency is still to shorten them. Smeaton was the first also to reduce the power of engines to an arithmetical measure. The number by which he denoted it, was formed by multiplying together the number of feet through which the piston travelled in a minute, the square of its diameter in inches, and the number of feet of water to which the pressure driving it was equivalent. Thus, if the condensation were such as to reduce the steam under the piston to 180° temperature or half the atmospheric pressure, which he found was about the best degree, the pressure acting to depress it was half an atmosphere, or equivalent to about 17 feet of water. Then if its speed were 80 feet per minute, and its diameter 20 inches, or area 400 *circular* inches, he called the power of that engine 17 × 80 × 400, or 544,000. This implied that the maximum of work to be obtained from it, supposing no friction, would have been lifting a column of water 20 inches diameter and 17 feet long, 80 feet high, per minute; or a column 1 inch in diameter and 1 foot long, 544,000 feet high per minute; or 544,000 such measures 1 foot high per minute. Now the pressure of a foot of water on a base of 1 circular inch, is, within a very minute fraction, one-third of a pound avoirdupois, so that Smeaton's dynamic unit denoted the power that lifts a third of a pound 1 foot high per minute. The power of his largest engine was 7,558,000 of these units.

Smeaton seems also to have introduced the regulator called the *cataract*, which still determines the number of strokes to be performed in all single-acting engines. We have said that the valve-gear, or that for opening and shutting, by the engine's own stroke, the passages of the steam and injection water, had been greatly improved, the objects being suddenness and well-timed closing and opening of their full area, at the moment each stroke ceased. To this end a bar hanging vertically from some part of the working-beam, was furnished with certain projections or *plugs*, that, at the proper moments, touched and moved the levers acting on the valves, and was from them called the *plug-tree*. This is now allowed only to act directly in effecting the changes that stop the working stroke of the piston and start its non-effective or up stroke. The next effective stroke is started by an action brought about thus:—The plug-tree in its ascent (or whichever motion corresponds to the piston's ascent) draws up, by a flexible chain or cord, a small plunger or piston enclosed in a small pump-barrel, standing with its foot in water, and called the cataract. The foot has a valve opening inward, through which of course water is by this action drawn in, as into a boy's squirt. It has also a valve opening outward, through which the same water may be expelled again, but not by the reversed motion of the plug-tree, because we have said this has only a *flexible* connexion with the plunger, or can pull, but not push it, *i. e.* raise but not depress it. The plunger then is left to subside by its own weight, or some weight with which it is loaded for the purpose, and only as fast as this weight can expel the water through the outward-opening valve. This must plainly always take an exactly equal time, as long as the weight and the area of that passage for the water remain constant; and when the plunger has sunk to a certain point, *it* (and not the plug-tree) is made to perform those changes in the valves that start the engine on its next working stroke. Thus the time between stroke and stroke depends solely on the weight with which the cataract plunger is loaded, supposing its outlet passage unvaried; but means are commonly provided for enlarging or contracting this passage; and by varying either this or the weight, the number of strokes to be performed in a given time can be regulated, and will remain unchangeable, and out of the power either of attendants or variations in the fire to affect. Steam may be generated faster or slower, but it will only, in one case, accumulate to a higher pressure, in the other

sink to a progressively lower pressure in the boiler; and though the working stroke be performed in a shorter or longer time accordingly, yet the number of strokes in a minute, and consequently the work done, and the quantity of steam and of heat expended, cannot vary, as long as the engine is working at all. Thus the attendant's whole task is reduced to keeping the boiler steam at a constant pressure.

In 1761 commenced the labours of that great philosopher and inventor, whose name must always be identified with the steam-engine, as the settler of its theory, the first who learnt to reason accurately on it, and therefore the completer of its economical reform, leaving henceforth only a moderate margin for the saving of fuel, establishing the principles on which all future improvements must be founded, and reducing all possible progress henceforth to matters comparatively of detail. Watt's first experiments, indeed, were unimportant, and it seems he did not recur to the subject, until required, in 1764, to repair (his business being that of a philosophical instrument maker) a small model of an atmospheric engine belonging to the University of Glasgow. The cylinder of this model was 2 inches in diameter, and 6 inches in length. His investigations into the causes of the failure of this miniature engine to imitate the working of large engines, led him gradually to a better understanding of the requirements of such engines in general, than any one else, even Smeaton himself, had yet realized; and after a series of experiments on the relation between the temperatures and pressures of vapour, (which were the first to show that fixed connexion between them which we have explained under Steam, where the results of these his measures will be found,) and after other experiments on the expansion of water in evaporating, which he estimated at 1,800 times, under the common pressure; and also on the time occupied or the surface necessary to evaporate a given quantity; and especially on the quantities of steam and injection water to be mixed for effecting a given reduction of temperature and pressure; he satisfied himself of these two points as most important to be aimed at in engine making: *first*, that the cylinder ought, instead of being alternately heated and cooled, to be kept if possible constantly as hot as the steam that enters it; and *secondly*, that notwithstanding this, the quantity and coldness of the injection water should be such as to form with the condensed steam a mixture not hotter than about 100°, so as to leave the vapour not more elastic than saturated steam of 100°, which we have seen supports about 1·8 inch of mercury. Smeaton, as already stated, cooled it hardly lower than 180°, at which temperature it supports 15 inches, and thus he lost half the atmospheric pressure, for the sake of avoiding the great waste of incoming steam that the sides of the cylinder would condense before the next stroke could begin, had the cylinder been allowed to become cold enough to produce a more perfect vacuum.

If a reader, ignorant of the steam-engine except from these pages, will now, with quite as much knowledge of steam and its properties as Watt had at the time to which we are now referring, endeavour to suggest how these two requirements are to be reconciled, he will appreciate the ingenuity and beauty of Watt's solution of the difficult problem, which, he says, occurred to him one day early in 1765, and afforded such a clue to the whole labyrinth of engine reform, that, in a few days more, the whole series of improvements which he afterwards carried out, had, in their principles at least, sprung up and become settled in his mind. His primary idea, on which the whole structure of the modern engine depended, was, that if instead of cooling the cylinder-full of steam by an injection of cold water, a communication were to be opened therefrom into *another vessel*, cold, void of air, and in which a jet or shower of cold water was diffused, the steam would instantly rush into this vacuous vessel, where, as fast as it arrived, it would be cooled, liquefied, or killed and got rid of, and thus the cylinder would be rapidly emptied *without necessarily being cooled a single degree*, its whole vapour being reduced to the *density* and *elasticity* of that in the cold condensing vessel, although remaining as *hot* as may be desired; and thus the piston being depressed by almost the whole atmospheric pressure instead of half, it could nevertheless be immediately driven up again on admission of fresh steam, the cylinder having hardly lost any heat, and therefore hardly wasting by condensation any of the incoming steam. But, turning now to the other vessel which we call the *condenser*, although it is evident that one much smaller than the cylinder would suffice to receive and condense all its contents, or ensure one stroke, yet it is equally clear that, as every stroke brings both more injection water, more steam water, and more heat into this receptacle, it cannot long retain, however large, either the vacuity or the coolness, which are the two essentials to the due performance of its functions; but must become at once more full of water, more hot, and because hotter, full of vapour of a continually higher density and pressure, until by approaching the pressure of that supplied to the cylinder, it would stop the whole action of the engine. Now the accumulation of heat, and therefore of elastic vapour, can be stopped by immersing this vessel in a running stream, or a tank artificially supplied with a continual influx of cold water, (as the tank that supplied the injection water always had been in Newcomen's engine, Fig. 2039,) provided only we could get rid of the hot water from within the condenser, as fast as it is formed there by the union of the injection water and steam. Watt's first idea for effecting this object, although never carried out, was simple and ingenious. A pipe was to descend from the bottom of the condenser, and dip into some large store of water 34 feet below it. From 32 to 34 feet of this pipe (more or less according to the weather) would always be full of water, supported by the atmospheric pressure on the water below, and forming in fact a water barometer, while the condenser itself would remain void of liquid notwithstanding all that enters it, which would flow away down this pipe, never accumulating higher than the column which

the atmosphere could support at the time. The objection to this is, that as all ordinary water contains air and gases which escape from it when either heated or relieved of the common pressure, both the steam and injection-water must constantly bring some air with them into the condenser, the former being mixed with what the boiler-water gives out in being heated, and the latter giving out its own air as soon as it enters the vacuous condenser; which vessel, therefore, and consequently the cylinder communicating with it, would soon contain air elastic enough to resist the whole atmospheric pressure that works the engine.

Foreseeing this, Watt next devised a pump to be worked by some part of the beam of the engine, and so contrived as to draw out of the condenser, at each returning or up-stroke, whatever air had accumulated there by the preceding condensation. In order to estimate its quantity, we must remember that the cylinder-full of steam, if exactly of the atmospheric pressure, or at the temperature of 212°, will occupy as water $\frac{1}{1700}$th of the capacity of the cylinder, but being usually of a somewhat higher pressure and density, we will assume it to occupy $\frac{1}{1200}$th. If the injection-water be 7 times this amount, which is a usual proportion, both together will equal $\frac{8}{1200}$ths or $\frac{1}{150}$th of the cylinder. Now the air released from any water rarely exceeds its own bulk, so that the water and air together (for if a pump be required at all, it may as well remove both) will be no more than $\frac{1}{75}$th of a cylinder-full, under the common pressure. The uncondensed vapour also, if the condenser be not much above the temperature of 100°, will be no more than would fill itself and the cylinder under a pressure of 2 inches of mercury, or no more than $\frac{1}{15}$th of their joint capacity under the common pressure. Thus we see how small a portion of the power of the engine need be absorbed in working this pump, for the whole power of any atmospheric engine is evidently just what would work, with its own speed, an air-pump of its own capacity, supposed to work without friction. It is equivalent to removing, at each stroke, its own cylinder-full of matter, against the common atmospheric pressure. Watt conjectured, therefore, and rightly, that to perform about a 15th of this work, would be a sacrifice well worth making in order to avoid the enormous waste of steam which in Newcomen's engines was condensed in heating afresh, after every stroke, the whole cylinder just cooled by the previous condensation; and the waste of power incurred by leaving, as Smeaton did, the steam only half-condensed, in order to avoid cooling the cylinder more than about 30°, thus leaving it elastic enough to counteract half the atmospheric pressure.

This the first of Watt's deductions from his study of steam, would alone have made the greatest advance ever made in increasing the efficiency of fuel. It alone would have enabled one pound of coal to do that which had previously required 3 or 4 pounds. But his circumstances, which prevented him for some years from carrying his ideas into practice, led to the development in his mind of many more improvements, so that the form of engine which would have resulted from this one alone, the atmospheric engine with a separate condenser and an air-pump, has never been executed, and thus leaves a hiatus in the regular progress of this great invention, otherwise so steady and gradual. Pursuing his principle of keeping the cylinder as equally hot and with as little dissipation of heat as possible, it next occurred to him that the water placed on the piston of Newcomen's engine, and the cylinder-full of external air descending into it at every depression of the piston, must greatly cool (and the former also wet) its interior, and lead to a condensation of the next incoming steam. The water used for the purpose of keeping the piston tight was therefore to be replaced by "oils, wax, resinous bodies, fat of animals," (eventually the only expedient used,) "quicksilver, or other metals in their fluid state," as the specification of his first patent cautiously provides. The cooling by the air itself that drives the piston, was not so easily remedied; and while his solution of this difficulty involved such entire changes as to make the whole a new engine on new principles, and to affect its whole future history, we believe it was not the only possible solution, nor eventually to be, as at present, the only one practised. It occurred to him that as the hot steam in the boiler exerts as much or even more pressure than the atmosphere, the top of the cylinder, instead of being open to the *atmosphere*, might be made open to the *boiler* only; that a portion of the necessary store of steam would thus do the work done by cold air in the old engine, and yet no more steam would be used on this account, because the same cylinder-ful that had done this work of depressing the piston, would afterwards be introduced under it, to be condensed and leave the vacuum against which the next cylinder-full would act.

This of course involved a tight covering to the mouth of the cylinder, with some contrivance for letting the piston-rod pass, without leakage, through its centre. But Sir Samuel Morland, the next experimenter after Worcester, had, in the previous century, invented the *stuffing-box* for such cases, a very simple and hardly improvable contrivance, not required indeed before this idea of Watt's, but without which the modern steam-engine could not exist. It simply reverses the elastic packing of pistons. They carry, in a cavity all round them, elastic matter to press *outwards* against the enclosing fixed walls. The stuffing-box is a similar cavity in the passage made for the rod, holding elastic matter to press *inwards* and clasp it round; and both alike have their want of contact made good by means of grease.

It was this great change, rendering the engine independent of any form of matter but *steam* to press the piston, that led to the present name *steam-engine*, being used to distinguish Watt's engine from Newcomen's as improved by Smeaton; and the term *atmospheric* engine on the other hand to distinguish the old from the new; while the former name, *fire-engine*, equally and correctly applicable to both, forthwith went out of use, as already noticed.

Yet another cause of unnecessary cooling, the ex-

posure of the *exterior* of the cylinder, Watt proposed to meet by surrounding it with a bath of steam enclosed in an outer case, communicating with the boiler, and now called the *jacket;* for although it might seem that this would enlarge the surface for cooling, and so dissipate more heat, yet he rightly anticipated that any condensation into moisture *within* the cylinder caused so much loss of power as well as of heat, that its avoidance was worth the incurring of a much larger amount of condensation elsewhere, as in the jacket, where it would be simply a loss of heat.

All these improvements—which together have quadrupled the effect previously obtained from any quantity of fuel—were settled in Watt's mind, as he said, within two days after the key to them, the separate condenser, had pointed out to him the way, and before trying his first crude experiment, in which a syringe of $1\frac{3}{4}$ inch diameter was his working cylinder. A large model with all these parts, and a wooden case for the purpose of better confining the heat of the jacket, was next made, but although perfectly demonstrating his success, he was unable to get these splendid innovations noticed until the year 1769, the date of his first patent. This patent embraces, in addition to the above improvements, a proposal to revive "in cases where cold water cannot be had in plenty," Leupold's plan of using only the excess of the steam's pressure over the air's, and discharging it without condensation; and also a "rotary engine" to make steam produce directly the circular motion required for most machinery, and supersede the pumping up water into a reservoir to drive a water-wheel by its descent, which Smeaton not only thought necessary, but even 12 years after this, defended by a doubt that any "motion communicated from the reciprocating beam of an engine could ever act with perfect equality and steadiness in producing a circular motion." This rotary scheme, however, like many others since patented, was a failure, and probably taught Watt (as it would be well if it had taught others) the really trifling importance of a problem on which more mechanical ingenuity, as well as money, seems to have been utterly wasted in the last half century alone than has gone to the whole development of the present steam-engine and its utmost complement of appendages and refinements.

The *single-acting* or *pumping engine* may be said to have been completed in all its essentials, by this first of Watt's patents, although it is now never made without borrowing from his later contrivances some refinements not strictly necessary to it, and a very few due to other improvers. His next patent, however, in 1782, introduced another great and new principle, second only to the former in importance, and perhaps excelling it in the saving of fuel which it may ultimately bring about; for although not even now pushed to its practicable limits, it has in some cases been carried to the point of making one pound do the same amount of work that required three pounds in Watt's original engines, or 12 lbs. in Newcomen's. This, which hardly affects the construction of the engine, being rather a new principle of operating than of engine-making, is called *working expansively*, and consists simply in cutting off the supply of steam from the boiler to the cylinder, when the latter has been only partly filled, or the piston partly depressed, instead of leaving this communication open until the stroke is finishing. The portion of steam thus shut into the cylinder and left to itself, will evidently still drive the piston, only with less and less force as it expands and becomes less elastic, and would continue to do so, until reduced to the rarity of the vapour below the piston, which alone resists it, and which is only as elastic as that in the condenser, cooled to about 100°, or about 15 or 16 times less elastic than boiling steam. Long before this attainment of equilibrium, however, the piston comes to the end of its stroke, and it is evident that the work done must be a greater fraction of what the same stroke would have done on the old plan, than the steam used is a fraction of the whole cylinder-ful. For, suppose we use only a third of a cylinder-ful of steam. It will, *while entering*, drive the piston one third down, and perform a third of the work done by a whole cylinder-ful on the old plan. But after this, *while expanding*, it will exert a power, continually diminishing indeed, but the whole of which is added to the above, and is therefore a clear gain on what the same quantity would have done by the old method. It has been proved by mathematicians since Watt's time, first by Mr. Davies Gilbert, that the saving possible by this expansive working is even more important than he seems to have been aware of. If the work done by any quantity of steam while entering the cylinder, or without expanding, be called 1, and it be then allowed to expand to any number of times its original bulk, then the quantity known as the *hyperbolic logarithm* of that number, will express the whole work done when it has expanded to that extent. For instance,

The hyperbolic logarithm of 2 is 1·69
" " of 3 is 2·10
" " of 4 is 2·39
" " of 5 is 2·61
" " of 6 is 2·79
" " of 7 is 2·95
" " of 8 is 3·08

We give these numbers because the discovery of them by calculation is too complex to be here explained. Now if we stop the entry of steam when it has half filled the cylinder, and allow it to fill the rest by expansion, as its expansion is into *twice* its bulk, the whole work done will be the hyperbolic logarithm of 2, that is 1·69 times what the same steam would have done without expansion; so that although a stroke thus performed evidently cannot effect what a stroke on the old plan would have done, yet *two* strokes of this kind (using the same steam as *one* non-expansive stroke) will do 69 hundredths more work than that did. And if, as in some Cornish engines, only an eighth of the cylinder-full be admitted, so that in eight strokes only a cylinder-full will be used, this will do 3·08 times the work it would have done if all had been admitted to perform one stroke; thus saving,

as compared with a non-expansive engine, full two-thirds of the fuel.

This will enable us to explain the difference of Watt's two modes of estimating and comparing engines, by the *power* and by the *duty*, which it is very important not to confound. The *power* means the quantity of work which an engine can effect *in a given time.* The *duty* means the quantity which it can effect *by a given expenditure of fuel.* The unit of time, for comparison of powers, is *a minute.* The unit of fuel, for comparison of duties, has hitherto been *a bushel of coals;* although no authority has decided what kind of coal, nor how many pounds of it shall be called a bushel, two points quite necessary to settle before the duties of engines can be truly compared. For both purposes, the unit of work done is a pound weight raised a foot high; and as Watt found reason to think, that the strongest horse is about equal to doing 33,000 times this work in a minute, he took this power (the lifting 33,000 lbs. one foot per minute) as a more convenient unit of power, to be called 1 *horse-power;* which it will be seen is equal to 99,000 of Smeaton's units. Thus, Smeaton having expressed the power of his Chasewater Engine by 7,558,000, dividing this by 99,000 gives a little above 77 H.P. on Watt's scale.

The *power* of an *atmospheric* engine was therefore simply proportional to its capacity of cylinder. For the portion of the whole aerial pressure not resisted by the cooled vapour was always a fixed proportion, (usually one half,) and it could never exceed what a perfect vacuum would give, (or double the *usual* power,) becoming then unalterable as long as the size of cylinder was unaltered. The power of Watt's or all later engines, however, can be increased without change of size, simply by increasing the pressure of steam, which of course, if the load remain the same, increases the speed of the piston, and so the number of strokes, and therefore the work done in a minute; and there is no limit to the power obtainable from the smallest cylinder by thus increasing the supply, provided only a boiler be found large enough to evaporate the increased quantity of water, and strong enough to resist the increased bursting pressure. Thus no particular *size* of cylinder or engine can now be reckoned as having this or that particular power, the power being now dependent, not on their size, but on their *strength, i. e.* the maximum pressure of steam to be safely borne by them. On the other hand, a boiler may and must have its power exactly defined, and depending wholly on *size,* (of evaporating surface,) and not on *strength* at all; for it is proportional only to the weight of water evaporated, or of steam produced per minute, and is no way affected by the density or pressure of the steam; the same weight of high-pressure steam driving a small piston, or of low-pressure steam driving a large one with equal effect. Thus a given number of horse-powers exact no particular size of *engine,* but an unalterable size of *boiler;* and this may be ever so strong or so weak, but the *stronger* it is, the *smaller* may the cylinder and machinery be, and *vice versâ;* its strength exactly defining both their minimum strength and minimum size. But as certain difficulties in the making and rivetting of the iron boilers now used, practically confine their strength to certain rather narrow limits, (for they cannot be thicker than $\frac{5}{8}$ths, nor thinner than $\frac{3}{8}$ths of an inch,) this in fact determines limits for the size of an engine of given power, or the power of one of given size.

Now as *power* has no reference to the goodness of an engine, or the economy or waste with which it is worked; so neither has *duty* any reference to time, or to the size and power of an engine. The smallest engine, that must work a month to fill a certain reservoir with water; and the largest, that will fill it in an hour, may be conceived to be just equal in point of duty; and they will be so if the small one have consumed no more fuel in this month than the large one consumed in the hour. This cannot be the case, however, with engines equally good, because there must unavoidably be more of the power of the small engine, than of that of the large one absorbed in *friction,* as well as more of its heat dissipated by *radiation.* We have seen that a piston having 4 times the surface of another, has only twice its friction; and a cylinder or boiler having 8 times the capacity of another, has evidently only 4 times its surface to radiate heat. So that large engines will always do somewhat more duty, *i. e.* more work with a given quantity of fuel. And of course, for this reason, any work is done more cheaply in a given time by one engine than by two or more equally perfect engines.

The reader will now see, that by Watt's principle of *expansive* working, the power and the duty of an engine must be oppositely affected. When one is increased, the other must be diminished. The utmost power is obtained from any given size of cylinder and pressure of steam, when it is worked without any expansion, but in such case the duty is least. By expansion to such an extent that the steam shall be admitted for only one-eighth of each stroke, the consumption of steam and therefore of fuel *per stroke* is diminished 8 times, or as 8 to 1, but the *effect* of the stroke is only diminished as 8 to 3·08. In this latter proportion is the *power* of the engine diminished; that is, it can perform *in a minute* hardly three-eighths of the work that it would have done with steam of the same pressure not expanded. But it will do *with a given quantity of fuel* 3·08 times the work that could, by the non-expansive method, be performed with the same quantity; and therefore its *duty* is said to be more than tripled. Now if it were required to preserve this duty, and yet do as much work per minute as before, *i. e.* to have as economical an engine as this expansive one, and yet as powerful as it was when used without expansion, this would only be possible with a cylinder more capacious as 8 to 3·08, supposing the steam in the boiler to be unaltered; or if the same cylinder were retained, the steam must be more elastic in the same proportion, so that either a larger engine or a stronger boiler is necessary if the same work is to be performed in as

short a time and yet more cheaply. Thus although a given power exacts only a definite size of boiler, and not any particular strength thereof, nor size of engine, yet every increase in either of these enables the engine to be worked to that or any smaller given power more economically, that is with a higher duty, because with more expansion. Hence the greatest duty or economy has been attained in the Cornish mining engines; which, of all others, are the most costly in construction, and largest in proportion to the power exerted, because using the highest pressure of steam in the boiler, but the lowest in the cylinder, and therefore requiring the strongest boilers, largest cylinders and machinery, and slowest motions. In these too the economy is greater, the more below their maximum power they are working, and therefore greatest when they are first erected, and continually growing less as the mines deepen and their work becomes increased. And this compensation between power and duty, or between the first cost of engines and their economy of fuel is inherent in the nature of steam, so that, other things being equal, the cheaper an engine be made, the more fuel must it continually consume.

Besides this principle of expansive working, Watt's second patent introduced the first successful application of steam to the production of rotary or *uninterrupted* motion, whence all other motions likely to be required may be derived. Papin, and many since him, had suggested or tried means for this, either by the direct action of the steam on some kind of wheel (which Watt himself was attempting at the time of his first patent, but had abandoned) or by arranging two common pistons to act alternately on a wheel or axle, each pulling it round while the other was being drawn back to its starting place by a weight disconnected with the revolving parts. Hitherto the means of doing this had been too circuitous, and it first occurred to Watt that the most ancient and common contrivance for getting continuous motion from an intermittent power, the turner's or knife-grinder's *foot-lathe*, offered the very best solution of the problem. The axle of a heavy wheel is bent into a crank, from which hangs a rod or cord down to the treadle, which (just like the in-door half of the beam of Newcomen's or any single-acting engine) is alternately depressed through a small arc by the motive power, and then left to ascend by the action of a weight, in this case attached to the wheel on the side diametrically opposite to the projection of the crank, as shown in Fig. 2042, but tending, like the weight at the out-door end of the engine beam, to draw up that which the motive power depresses. The crank and wheel are pulled round half a turn by the excess of the motive power over this weight, which is thus brought to its highest point, and then its descent carries them round the other half turn; and not back by the way they came, because the *momentum* acquired by the revolving parts, especially the rim of the wheel, carries them past the points where the weight is at the top or bottom of its circle, or where it has no tendency to turn them either way.

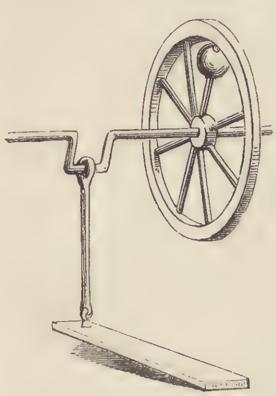


Fig. 2042.

It is evident that such a wheel, weight, and cranked axle, placed over Newcomen's open cylinder, might be kept revolving by a rod or chain from the centre of the piston, pulling them half round, as the piston is depressed by the air, like the lathe treadle by the foot. But Watt, by closing the top of the cylinder with a lid and stuffing-box, had prevented this by constraining the piston-rod always to keep upright and to move in one vertical line. Its top might indeed be jointed to another rod or a chain of some length whose top would be free to follow the circle described by the crank, but this would raise the latter to an excessive height. It was easier to retain Newcomen's beam, and let the crank rod or chain descend from its out-door end to an axle situated below it, or about level with the cylinder,—and pull the crank round its *upward* half-turn, while a weight on the same radius as itself would carry it round the other half. But the weighted wheel on a large scale being cumbrous, Watt first thought that it might be possible to dispense with at least the one-sided weight, if not the whole wheel, by having *two*, or still better *three* engines acting on as many different cranks formed on the same axle, but in opposite directions if there were two, or in directions 120° apart if there were three; the advantage of three being that each engine would begin to act *before* the preceding one had ceased, instead of at the precise moment of its ceasing. But he finally abandoned all these plans in favour of the capital conception of a *double-acting* cylinder, that is, a method of so using a single cylinder as to make it serve the purpose of two acting alternately, the piston not simply returning passively to the end at which its working stroke begun, in order to be ready for another, but being driven back precisely as it was driven forward, so that both up and down strokes may be equally effective, and not a moment pass in which the steam is not working, whereas in the single-acting engine it can never be working more than half the time.

To explain the changes necessary in the valves for this purpose, Fig. 2043 shows their arrangement for the single-acting engine. There are three principal valves which are opened independently of each other by raising their respective spindles S, Q, and X, which pass up through stuffing-boxes, and are either drawn and kept up by weights, except when depressed by the valve-gear of the engine, or else they are kept down by their own weight, except when the valve-gear lifts them. In any case, whenever the *steam-valve*, the rod of which is shown at S, is open, as in the

figure, there is access from B, or from the boiler to the top of the cylinder; the valve, whose rod appears at Q is shut, but that at X open. Under these circumstances, during the first stroke, the air of the cylinder is *expelled* through the condenser V and the

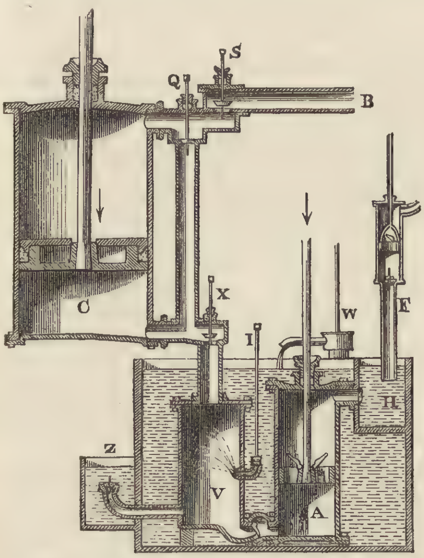


Fig. 2043. STEAM WORKING PARTS OF WATT'S SINGLE-ACTING ENGINE.

blow-valve Z; after which, during any other stroke, the steam under the piston is *exhausted* into the condenser, and a vacuum, *i.e.* vapour, as rare as that of the cool condenser, is left at C, for the pressure above the piston to act against with full effect. When this has descended a certain portion of its stroke, which portion is said to be performed *with full steam*, the steam-valve S is shut, and the steam already admitted expands so as to drive the piston the rest of its course; and when it is very near the bottom, the exhaustion-valve X is shut, and then the valve Q is opened. This puts the two ends of the cylinder in communication with each other, and thereby equalizes the pressure on both sides of the piston, whence it is called the *equilibrium valve.* The piston is then simply drawn up by the counterweight, the cylinder-ful of steam passing from above to below it; and immediately at, or rather before reaching the top, Q is again shut, so that a little steam shut in above the piston may act as a cushion to prevent its violently striking the top of the cylinder, and then the steam and exhaustion-valves S and X, simultaneously opened to produce another down-stroke. It will thus be seen that the cylinder, instead of requiring a foundation to stand on, has to be firmly kept *down* by beams across its top.

The remaining apparatus, namely that for disposing of the spent steam, consists of the cold-water cistern, in which the condenser V is immersed; the injection-cock, which is opened or closed by the rod I, and may either be open during the whole working or only during the effective stroke (the amount injected to produce a given degree of vacuity being rather less in the latter case); and three pumps, A, W, and F, worked by the beam of the engine. W is the *cold-water pump*, by which all the water used is raised from a well and poured into the cistern, whence some may overflow to prevent it from becoming too hot, and the rest is admitted by the jet into the condenser. A is the *air-pump*, usually equal in capacity to the condenser, from which it is to remove at each stroke the mixed contents of air, water, and low-pressure vapour that would otherwise accumulate therein. In the passage, from the foot of the condenser into that of this pump, a valve is seen, opening towards the latter. Two other valves open upwards through the pump piston, and another valve from the top of the pump into the small reservoir H. While the pump piston is being raised, the air and water above it are expelled into H, the valves of the piston itself being kept shut by the pressure on them, and a vacuum, A, is left under it, so that however rare the contents of the condenser, they open the lower valve, and half of them pass into A by the time the piston is at the top. The piston then descends, and the fluids beneath it, being compressed, instantly shut this valve, and, being unable to return through it, must soon become by compression sufficiently elastic to raise the valves of the piston, as shown in the figure, and, by the time the piston has descended to the bottom, the fluids pass wholly above it; where, on its return upward, they are compressed between its valves and the lid of the pump until they are sufficiently elastic to open, against the atmosphere, the valve leading into H, and so escape, the air and vapour into the open air, and the hot water to accumulate in H, which is hence called the *hot well.* From this, as much of it as was due to the condensed steam, usually about an eighth, is drawn by the third and smallest pump F, to supply the boiler, whence this pump is called the *feed-pump.* The remainder of the fluid that enters H, namely as much hot water as was injected cold into V, overflows in waste; we say, *in waste*, because it carries away all the heat that was communicated, in the boiler, to that 7th or 8th part of it which, as steam, was directly employed in working the engine. The diffusion of this heat from a certain quantity of aqueous matter to about 8 times that quantity, is the source of all the motion which the engine has imparted. In diffusing itself from the waste water to still more matter, it will produce still more motion;—and it would have produced as much motion altogether, on air or smoke or other matter, had the same fuel been simply burnt away in an open fire. So much fuel burnt produces so much heat; and this, in spreading through so much matter, produces so much motion. The steam-engine does but collect and utilize a part of this motion.[1]

(1) It must be remembered that however much of the *motion* be utilized, all the *heat* remains either in the waste water or in the waste steam; all the *quantity*, only diminished in *intensity*. It can therefore, in any purpose to which it is still applicable, whether chemical or physiological, do all the work that it could have done before passing through the engine. The diffusion of heat through more matter does not render it capable of doing less, in total quantity, but only of doing fewer kinds of work. Every kind of work done by heat exacts indeed a certain intensity thereof, and

Now, in the double-acting method of using the same cylinder, Watt's object was to make the up-stroke an exact counterpart of the other, so that as the piston has been driven down by the pressure of steam above it against the almost powerless vapour of the condenser (or what is commonly called the *vacuum*) below it; so an exact reversal of this, access from the boiler to *below* it, and to the condenser from *above* it, may drive it up with exactly equal force. Fig. 2044 shows one of his methods of making valves to do this, and also the remaining parts of his double-acting engine, except the beam to which the various rods are attached above, and the boiler which, being usually in a separate building, need not be represented, but must be imagined to supply the main steam-pipe *a*. This terminates in the side of an upright cylinder *b b*,

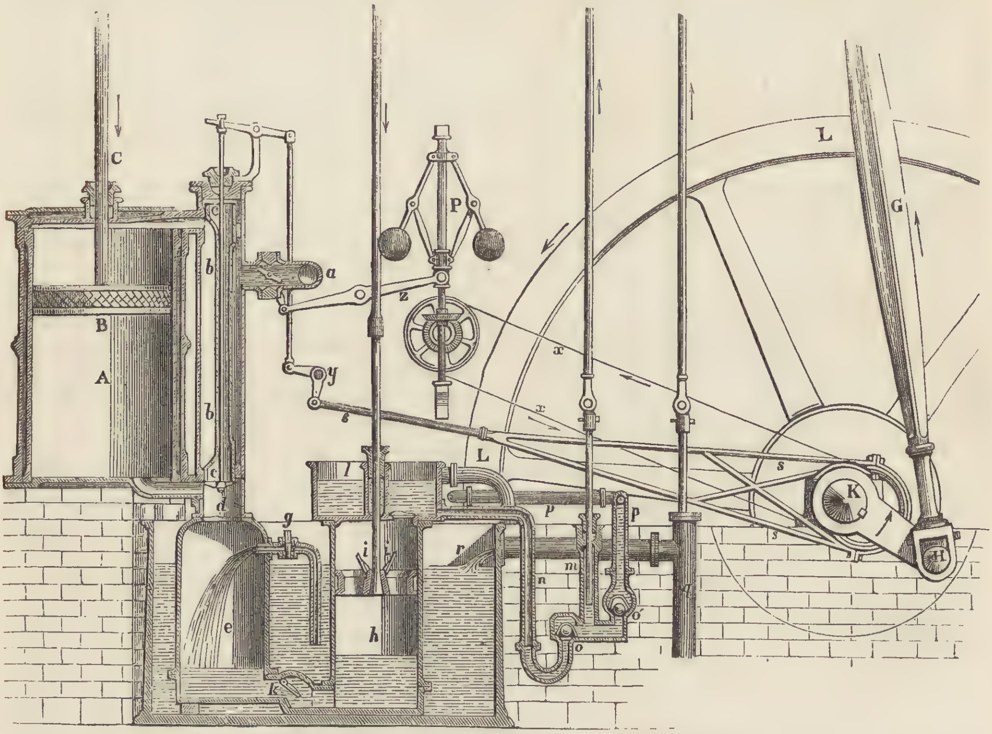


Fig. 2044. WORKING PARTS OF WATT'S DOUBLE ACTING ENGINE.

longer, but much smaller than the working cylinder, into which it has two passages *c c*, called the top and bottom *ports*, and its foot communicates freely by *d* into the condenser *e*. This vessel, *b b*, called the *steam-chest*, encloses a shorter tube *c c* of about half its own area, open at both ends, but enlarged at both, so as to fit by the aid of elastic stuffings the interior of the chest, in which it is raised and depressed through a small space by a rod passing out through a stuffing box at the top, and worked by the valve-gear. In the figure, the top and bottom enlargements *c c* of this inner tube are slid *above* the respective ports, so that there is a free passage from the lower port into the condenser; but the steam from the boiler which *surrounds* but cannot pass *into* the sliding tube, finds open way to the upper port only, and by pressing on the top of the piston, produces the down stroke as in the old engine. This done, the inner tube *c c*, or

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involves a certain diffusion into more matter, yet no more than might leave it still intense enough to be applied to some other kind of work. Thus the heat from almost any kind of burning fuel has, at the moment of its evolution, an intensity beyond all our present means of measurement, and would be capable of doing anything we require, even to the melting of platinum, if we could only catch it soon enough. This is the only reason why we get more heat by combustion in pure oxygen than in air, viz., that we catch it before it spreads through the nitrogen which is mixed in the air. Now, let it once spread beyond its native atoms far enough to have only the intensity which we call 3,000°, it can no longer melt any platinum, but it can melt just as much iron as before. Let it spread until reduced to the intensity indicated by the expression 2,000°, and although it can melt no iron, it can still melt as much brass as ever. Let it pervade twice this matter, or sink to the intensity 1,000°, it will melt no brass, but it will melt as much zinc as ever. Again, diffused through twice this mass, or reduced to heat of 500°, it will not melt zinc, or lead, but it will distil as much palm-oil as ever. Shared by more, until its intensity is 250°, although it can perform none of these operations, it can boil as much water, or raise as much steam of any pressure under two atmospheres, as ever. At 200° it can raise no useful steam and cook no meat, but it can brew as much beer as ever. Spread too far to brew, it will boil as much sugar in vacuo as ever; too far for this, it will hatch as many eggs as ever: when too diffused for the hatching of an egg, it will force as many pine-apples as ever; and when it will not aid fancy horticulture, it will do better: it will warm as many dwellings as ever. Thus it is probable that if the heat of smelting and of a few such operations alone, were made the most of, instead of being thrown away after serving a single purpose, none of the fuel burnt to raise steam-power, to cook, to brew, to wash, or to warm buildings, would be needed. We waste most of the heat produced even by that moderate portion which we cannot yet contrive to throw away bodily in the shape of gas from coking ovens and soot from chimneys. Of course, any system that throws a nation on its mines for support, can have but a lease of life limited at the furthest by their extent.

slide, is pushed down into the position of Fig. 2045, so that its lower enlargement may stop the way from the lower port to the condenser, while the upper one stops that to the upper port from the boiler, but it opens a way from that port down through the inner tube to the condenser, while the steam surrounding it finds access by the lower port to press the underside of the piston, and produce the up-stroke that was required.

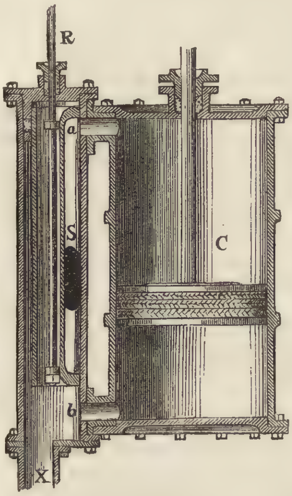


Fig. 2045.

The after-disposal of the steam-water, condensing - water, and their released air, is precisely as in the single-acting engine, except that all the vessels through which they pass must, to maintain the same rarity of vapour, be (for an equal cylinder) twice as capacious, as must also the boiler; or rather we should say that, for the supply of the same power, all these parts must retain the same dimensions as if the engine were single acting, only the *cylinder* being reduced in capacity one-half, because capable, in half its former compass, of using the same amount of steam, and of course yielding the same power. If the pumps were made double-acting, (as some for other purposes have been since Watt's development of this principle,) they too might be proportionably reduced, but neither Watt nor any later mechanician appears to have found the saving worth the complications necessary for that end.

We have represented, however, in Fig. 2044, some variations now generally adopted in the hot well *l*, and feed-pump *m*. The former usually occupies the top of the air-pump *h*, in order that it may be quite disconnected with the cold water cistern, and either the whole lid of the air-pump, or a portion of it, as shown in the engraving, opens as a valve when the air-piston has in its up-stroke sufficiently compressed the fluids above it, to lift this valve and drive them out. From the top of the hot well proceeds the waste pipe, and from a lower point the pipe *n* to the feed-pump *m*. This is now, owing to the high and variable pressures of steam used in modern boilers, made to force its supply directly into them, instead of merely lifting that supply, as in Watt's engines, into an open reservoir of such a height above them that the column descending from it should balance the excess of the pressure of the steam above that of the external air; then rarely exceeding a third of an atmosphere, but now sometimes amounting to three or four atmospheres, which would support an unwieldy height of water, and by a slight increase, drive it to overflow like Worcester's fountain. The present feed-pump, therefore, is a forcing or solid-piston pump, and usually of the kind called a *plunger* pump, (as shown in Fig. 2044, and similar in principle to the pump of Marly, described under PUMP, Fig. 1777,) the rod that descends through the stuffing box being large enough to occupy nearly the whole barrel, so that, by *plunging* into the water (whence its name) it must drive out a considerable portion, which can only escape by lifting the valve *o′*, (here shown as a ball valve or hollow ball, loosely resting in a conical seat,) and transmitting its pressure along the *feed-pipe p p*, which is always full, to the boiler, which receives at each stroke a supply equal to that which the plunger displaces. But in rising, the vacancy which it would leave is supplied by water from the pipe *n*, lifting the ball valve *o*, which is similar to *o′*, and as neither of these valves will admit the return of water once forced through them, every up-stroke draws water from the hot well into the pump, and every plunge forces it on towards the boiler. The larger pump *q* used for pouring cold water into the cistern at *r*, still resembles in structure one of the common domestic kind. [See PUMP, Fig. 1772.]

It will now be evident that the connexion of the double-acting piston rod C with the beam above, can no longer be by any sort of chain as in Newcomen's, because it has not only to pull down the beam, but to push it up; and as it is constrained by the lid of the cylinder to move always vertically, its top evidently cannot be simply attached to any point of the beam, which describes an arc; but by supposing the sector fixed on the beam, as on Newcomen's, in Fig. 2039, to be cut with teeth, and the straight prolongation of the piston-rod with similar teeth interlocking with them, the desired end would be answered, since the piston-rod would be exposed to no bending strain. Watt's better contrivance for this purpose we reserve for later explanation, and proceed at once to the rotative part. From the other end of the beam hangs the *crank-rod* G, Fig. 2044. It is thickened towards its middle, in order to stiffen it against bending without waste of material. Now, by alternately pushing down and pulling up this crank-rod, the crank H continues its rotation when once begun, because the momentum of the rotating mass carries it across the two *dead* points as they are called in each turn, where the crank is upright or downright, and at which also the piston being at the top or bottom of its stroke, is exerting no force. In order to produce sufficient momentum for this effect, however, the quantity of matter revolving has to be increased by attaching to the axle a wheel with a heavy rim L L, called the *fly-wheel;* and as the efficiency of this in equalizing the motion, depends on the *quantity* of motion that it stores up, as it were, or absorbs in order to give out again whenever the velocity tends to decline, it follows that the larger the wheel, the less matter may it contain; because, with the same time of revolution, the velocity of its rim, (which is chiefly concerned in storing up momentum,) will obviously increase as its circumference, *i.e.* as its radius; and 100 lbs. moving

20 feet per second, will have the same momentum as 200 moving only 10 feet per second. [See STATICS and DYNAMICS.] In order to save material, therefore, the wheel is made as large as the situation will conveniently admit, unless this would lead to a rim moving faster than 60 feet per second, beyond which its centrifugal force would endanger the flying apart of the cast metal, of which it is composed. The momentum of fly-wheels is found sufficiently to equalize the motion, when so calculated that, if the engine suddenly cease working, the power then yielded by the wheel shall be from 3 to 4 times what the piston without a fly-wheel would accumulate in travelling from rest to its greatest speed.

Some persons who do not sufficiently regard the fundamental laws of motion discovered by Kepler, Newton, and Galileo, have imagined that force is lost in circularising the motion by means of the crank, or in regulating the motion by means of the fly-wheel. Such is not the case. The only forces that can absorb or destroy motion or motive power, in machines whose parts do not *strike* together, are friction and the resistance of the air. Without these, the greatest mass, a planet for example, once brought to move with a given speed, would require no fresh supply of force to keep up that speed; the smallest added force would accelerate and continue to accelerate it as long as it acted. The action of gravity upon a stone falling to the ground is a familiar example. What we call *moving* power should always properly be called *accelerating* power; and whenever it or any of it appears to be expended only for the purpose of keeping up a motion uniformly, neither doing work, such as lifting, cutting, spinning &c., nor accelerating the machine, such a moving or accelerating power is really employed in opposing and simply balancing friction, and the resistance of the air; which indeed, in some cases, as in that of a train on a level railway, form in themselves the whole work to be done. Now, the crank and the fly-wheel contribute their share, with the other necessary parts of the steam-engine, to both these resistances, but it is a most insignificant share. The wheel by its weight adds to that with which the axle presses on its bearings, and thus somewhat increases their friction; and the displacement of air by its spokes might be wholly obviated by having no spokes, but a flat disc; while the crank involves the *absolute minimum* of both losses, which is possible in a conversion of one motion into another. It is one of those cases in which the simplest, most obvious, perhaps earliest solution of a problem, is so obviously also the best, that, like many a contrivance of unknown antiquity, (many a feature in old architecture for instance,) by no progress of art or science can it possibly be superseded or suppressed unless the work become one of mere ornament or display.

Among the incongruous results of the system of patents under which steam machinery has grown up into its present state, none is more remarkable than that which impelled Watt for some years to use a ridiculously circuitous substitute for this ancient and universal element of the simplest machines, the crank, which a rival had actually managed to purchase the monopoly of, so far as its application to the steam-engine was concerned. He might almost as well have had the monopoly of using screws in steam-engines, or of using iron instead of copper in boilers. The effect of this monopoly was to compel Watt to employ that useless invention of the "sun and planet wheel," which, having at once disappeared on the expiration of the patent above referred to, we need not describe, notwithstanding its great ingenuity.

The fly-wheel, although correcting the increase and decrease of power necessary in every single stroke, and the total cessation thereof at the moment of changing the stroke, with other short irregularities, cannot evidently regulate or at all affect a change of the velocity of the engine to a new velocity continuing for many strokes to be different from the former, or gradually increasing or diminishing. Such may arise from a change in the firing and production of steam, in the degree of coolness or of vacuity in the condenser, (which may be affected even by changes of temperature in the weather), or what is most common, a change of the *load* or resistance offered by the work performed. Momentum can only soften down too sudden variations, as a *smoother*, not a leveller or absolute equalizer or *governor* of the speed, such as the cataract is to the single-acting engine. For such a *governor* Watt found a principle ready developed in an ancient appendage to windmills. Merely translated from the carpenter's into the iron machinist's style of workmanship, this gave the feature marked P in Fig. 2044. An upright axis is made to revolve quickly, (in this case by a small bevelled wheel at its foot, driven by a larger vertical one, which is fixed to a pulley receiving motion by an endless cord *x x*, from a similar pulley on the main axle K:) to the upper part of this vertical spindle, are suspended by joints, the two pendulums ending in balls, so that when at rest, they touch the spindle, and when it revolves, they fly out until their centrifugal force balances their weight, which of course happens further off the more rapid their motion. Two bars of half the length of the pendulum, jointed to their centres, hang down and are jointed at their lower ends to a collar freely sliding up and down the spindle, but obliged in so doing to raise or lower the lever Z, whose other end adjusts the degree of opening of the *throttle valve* in *a*, or that which the steam first encounters in extending from the boiler, and by which it is shut off, or admitted to work the engine. Whatever leads to an acceleration of the engine, causes the balls to fly out further or higher, thereby drawing up the collar that moves the lever *z*, and this is so arranged as to cause a *throttling* or reduction of the steam-way in *a*. On the other hand, any sinking of the balls through insufficient speed, must cause a wider opening of *a*, and increased supply of steam. There is an invariable relation between the time of revolution of such a pendulum, and the vertical depth or axis of the cone described by it; that is to say, whatever the length of the pendulum itself, it becomes so inclined,

that the depth from its point of suspension to the plane of the circle described by that point in its mass called the *centre of oscillation*, will always be the same for the same period of revolution; being equal to the length of a common pendulum that vibrates to and fro in that same period; and depending solely on the amount of the force of gravity, which is measured at any place by the distance a body falls in a second: so that, to the distance fallen in any given time, the length of pendulum vibrating in that same time, bears a constant ratio, viz. as the square of the diameter of a circle to half the square of its circumference, or as 1 to 4·9348. Now the depth fallen in a second hardly varies anywhere to a barleycorn more or less than 16 feet 1 inch, (the variation being due only to the earth's centrifugal force), and 16 feet 1 inch is 4·9348 times the length of a pendulum vibrating seconds, (*i. e.* to and fro in *two* seconds). So this length, viz. 39·1393 inches, is also the depth of the cone in which the *conical* pendulum or *governor* will revolve once in two seconds; and the measure of either kind of pendulum being as the square of the time, a *quarter* of 39·1393 is the length of a *half*-second's pendulum, or depth of a governor revolving in *one* second. So when the number of turns which the governor is to make in a minute is decided on, the depth of cone at which the lever *z* shall keep the valve *a* at its mean degree of opening is also decided on; and by so adjusting it, the governor can hardly vary from this speed, so that the number of revolutions of the axle K, or strokes of the engine, is also made invariable. Thus an excessive production of steam will only accelerate it to the very small extent required to lift the collar of the governor as far as shall so reduce the steam-way at *a*, as to keep back this surplus steam in the boiler, where it may attain any pressure, even to the lifting of the safety-valve, rather than allow the engine to be accelerated. And however slowly it be produced, as much as ever will be used at each stroke, owing to the increased area of opening allowed it at *a*, until the boiler is emptied of steam, or the diminishing pressure warns the fireman to accelerate its production.

With regard to the moving of the slide *cc*, necessary to change each stroke, it is now found most simple in all rotative engines to derive this movement not from the beam but from the axle K, because the slide must evidently not rise when the piston or beam rises, nor yet when they fall, but be moving fastest or in the middle of its stroke when they are stopping or changing their motion, and itself stop (and if possible remain unmoved for a time) when they are moving fastest. In Fig. 2044, a wheel is fixed on K behind the crank, with its centre not in the centre of the axle, whence it is called an *excentric*, and is embraced by a metal ring forming the extremity of the light framed piece *s s s*, called the *excentric-rod*, which must evidently, as the excentric revolves, be shifted alternately to the right and to the left through a space equal to the diameter of the circle described by the centre of the excentric, or twice the distance thereof from the centre of the axle. The end of the excentric-rod is jointed to a short arm hanging down from a horizontal axis or *arbor*, seen cut through at *y*, and which is thus made to reciprocate through about a quarter of a turn and back again. From another part of the arbor projects a similar arm in another direction, (which is here equal to, but may be longer or shorter than the first,) and this is jointed to an upright rod which lifts and pulls down, at its upper end, a lever that acts on the rod of the slide *c c*. The arrangement is shown needlessly circuitous, in order to combine examples of the various methods used for changing the directions of these reciprocating motions, which are in hardly two engines conveyed exactly alike.

We must now see how Watt met the difficulty he had created by obliging the piston rod to rise and fall in one straight line, and yet move the end of the beam through a circular arc. It *might* be met as already stated by cutting teeth on Newcomen's sector (seen in Fig. 2039,) and substituting for his chain a similarly toothed straight extension of the rod, such as is called a *rack*. But it was Watt's object to banish from his engine everything approaching to a blow of one part against another, or indeed an alternate contact and separation of any parts but the valves and their seats, where it is unavoidable. The most perfect and lasting machinery is that in which no surfaces, or portions of surfaces even, are allowed to work together without remaining *constantly* together, like an axle and its bearing, or the excentric and its enclosing hoop; and although this perfection can seldom be attained in the contrivance of machines necessarily very complex from the variety of their functions, yet all toothed wheels and racks should be avoided where constantly-touching gear is possible.

The *parallel motion* is the name given to the arrangement for effecting this, and it is founded on the following principle.—If, on the two centres A and *a*,

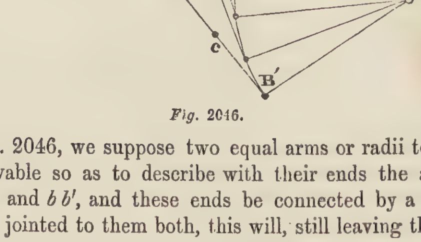


Fig. 2046.

Fig. 2046, we suppose two equal arms or radii to be movable so as to describe with their ends the arcs B B′ and *b b′*, and these ends be connected by a stiff rod jointed to them both, this will, still leaving those ends to move up and down their circular course, be itself so moved thereby that its *middle* point will describe *very nearly* a straight line, *c c*, as seen by the dots marking its centre in several positions. The course would be *quite* straight were each radius arm always to move through the same angle as the other

does, but as their ends would then plainly not preserve an invariable distance apart, the connecting piece, by obliging this, prevents that strict correspondence, and this is the only reason its own centre deviates a little to the right and left of a straight course, into an almost imperceptible S curve. Now if the arms be of such length that the arcs described by their ends

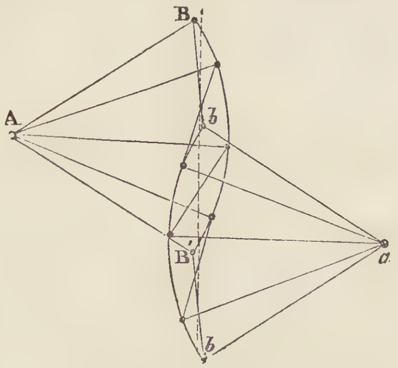


Fig. 2047.

interfere as in Fig. 2047, the same thing will hold good (which might not have been obvious without first considering the other figure), and the straightness of the course of the third bar's centre will be much more nearly attained ; as a trial of the drawing on a large scale will prove. The motion may be continued as far up and down as to make the connecting bar, when at B *b*, or B′ *b*′, incline as much to the *left* as it does when in the middle position to the *right*, and the top, middle and bottom places of its centre will be in one straight line. At two other positions rather nearer the top and bottom than the mean one, the bar will be vertical.

This arrangement is in fact the first of the two forms of "parallel motion," introduced by Watt into his beam engines. But it is not necessary that the two arms A B, *a b*, be of equal length. One arc may be more curved than the other, provided the point taken in the connecting bar be no longer in its centre, but nearest to that end which describes the less curved arc, or which has the longer radius. Mathematicians have taken much pains to investigate this problem, and various rules have been given for calculating from the ratio of the two radial arms the ratio in which the connecting bar should be divided by the point to which the force of the engine is applied, so that this point may most nearly keep (as it can never quite keep) a straight-lined motion; and the rule chosen by Tredgold as the best, when put into the form of a geometrical construction, appears thus,—Let C *c* Fig. 2048,

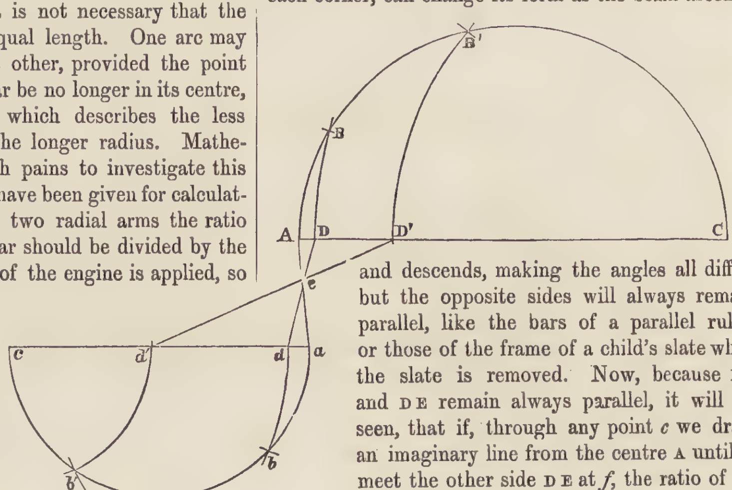


Fig. 2048.

be the two centres of motion, and C A, *c a*, the lengths of the arms, represented in their mean position, the only one in which they are parallel. Find the centre of each, and describe on it a semicircle. Then take any distance A B, on one semicircle, and an *equal* distance *a b* on the other, and from C and *c* as centres draw the arcs B D and *b d*, that is, transfer the distance C B to C D, and *c b* to *c d;* and a straight line joining D and *d* will cross the connecting bar A *a* in the point *e*, which is the one required. If any other equal distances had been set off on the semicircles, as A B′ and *a b*′, then, unless the latter cut off too much (say more than half), of the smaller semicircle (as this does to show the extreme results), the new line D′ *d*′ will cut so nearly in the same point *e*, that the difference may be neglected.

Now suppose we have two radial arms thus connected, one of them, A B, Fig. 2049, being the half of

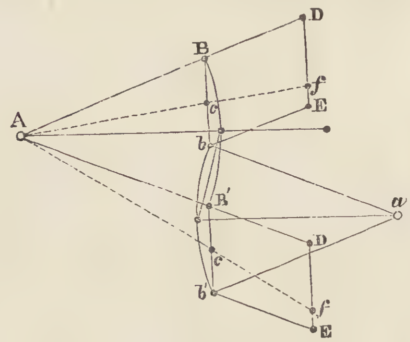


Fig. 2049.

the beam of an engine, and the other *a b*, an equal or shorter arm turning on a fixed centre *a*, for the purpose of rectifying the motion of a point *c* in the connecting bar B *b*, and suppose we lengthen the beam to D, and then take two more bars, one D E equal to the connecting bar B *b*, and the other E *b* equal to the prolongation of the beam B D, these four portions will form a parallelogram B D E *b*, which, having a joint at each corner, can change its form as the beam ascends and descends, making the angles all differ, but the opposite sides will always remain parallel, like the bars of a parallel ruler, or those of the frame of a child's slate when the slate is removed. Now, because B *b* and D E remain always parallel, it will be seen, that if, through any point *c* we draw an imaginary line from the centre A until it meet the other side D E at *f*, the ratio of A *c* to *c f* must remain always the same, though both vary in length as the parallelogram changes its form;—and hence (by a principle familiar to those who enlarge or reduce maps or drawings) the paths described by these two points *c f* must,

whatever their form, be similar, one being a mere enlargement of the other. So, as there is one point in B *b* made to describe a very nearly straight course, a line from A, through this point *c*, will give us another in D E with the same property, and available for receiving the motion from the piston-rod, while *c* serves to hang from it one of the pump-rods which does not need so long a stroke. This second kind of parallel motion, then, is a mere addition to the first kind, which always exists in the same arrangement whether used or not.

Commonly, both are made use of in the engine-end of the beam, as shown in Fig. 2050. The two *hanging-*

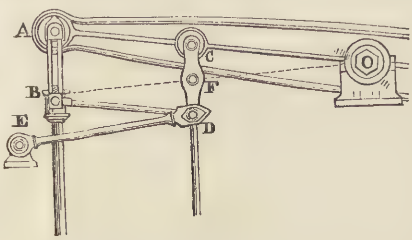


Fig. 2050.

links, A B, C D, are each double, with the beam between the pair. Their lower ends are connected by the single piece B D, and two *radius-rods*, like D E, nearly or exactly equal to O C, are applied one on each side of the whole, and move on a fixed centre at E. Therefore the middle of C D is the point to which to attach the air-pump rod, and an imaginary line from O through this last joint F, points out the place B for the attachment to the head of the piston-rod, which passes down between the two bars, of which D E is the visible one.

Such is a brief account of the more important improvements made by Watt in the steam-engine, whose history has been truly said to terminate with his labours; although later refinements in detail are innumerable. The double-acting engine, which has commenced so mighty a revolution in the whole of human works and ways, that nothing since the death-dealing invention of the 14th century seems, as a *causal* discovery, comparable with it, and we are utterly astounded in any attempt to realize the vastness of the completed change which it must bring about,—the double-acting engine can hardly be called more perfect now than when Watt left it. The single-acting engine, being required on a vast scale of size and permanence by the Cornish mines, has made the greatest advances since his time, and is now the more perfect engine in its kind, although the more complex also.

Fig. 2053 is the side view of as much of the modern Cornish engine as can be made distinct on so small a scale.

The cylinder C is not only furnished with double walls and a space of about an inch between them full of steam, but outside this is a much larger enclosure, (not shown in the figure,) confining a considerable thickness of ashes, by which the heat is so well retained as hardly to be felt in the building containing it. The top also has a covering of steam, and above that a covering of enclosed air or ashes. The piston which in Watt's time was made tight by surrounding it with a hempen gasket or flat rope (seen in Figs. 2044 and 2045) soaked in tallow, is now made entirely metallic, which was first done on the principle of A, Fig. 2051, a number of steel springs, around a

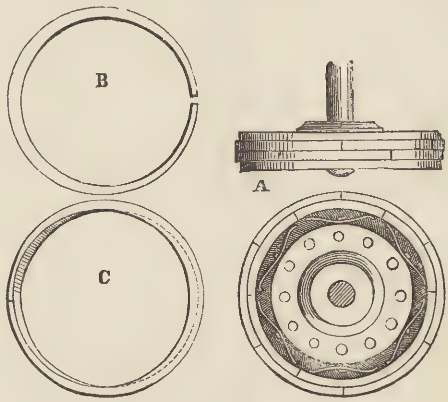


Fig. 2051.

central solid core, pressing out one or more rings of separate segments; and these being in at least two layers, one over the other, that the steam penetrating the intervals of the first set might be stopped by the second. After almost innumerable variations in the springs and arrangements for equalizing their pressure, engineers seem at length to find that all are excelled by the method of substituting entire rings made like B, thicker on one side, and about a hundredth part larger than the cylinder they are to enter, then cutting out a small portion, as shown in the figure, and bringing the ends into contact, so that it forms its own spring, and two of these hoops, laid one on the other, as at C, and kept together by an upper and lower plate, rather smaller than themselves, complete the piston; a progress from complexity to simplicity, singularly rare in steam machinery, and which we cannot but think must eventually become more aimed at than at present. Although each ring does not press out with equal force at every part of its circumference, and would therefore tend to wear the cylinder *oval*, this is very nearly corrected by placing the junctions at 90° apart.

Valves of single-acting engines are never *sliding*, as that in Fig. 2044, but lifted up entirely from their seats, to effect as sudden and complete an opening as possible, and to this and their accurately timed periods of opening and closing during the long slow stroke, much of the superior duty of the Cornish over that of all sliding-valve engines may, we believe, be attributed. But it was soon found that mere flat conical-edged valves, like those in Fig. 2043, to admit the steam fast enough, required so large a surface, that the power absorbed in opening them against the pressure of the steam would be a considerable deduction from that of the engine, while even in small engines none could be opened by hand without great assistance from levers or other mechanical powers, and therefore very slowly. A capital contrivance, called the *double-seat* valve, of which Fig. 2052 is a

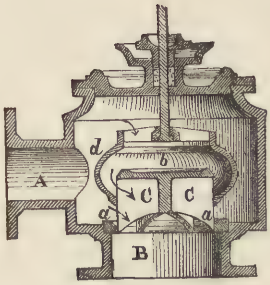


Fig. 2052.

section, obviates this, and is quite essential, and has long been used in all the Cornish engines. In the aperture *a a*, which is bevelled round to form the usual valve-seat, are fixed 5 or 6 thin vertical plates, of which C C are 2, radiating from the centre and supporting the flat disc *b*, the edge of which is also bevelled conically to form a second seat. The valve itself, or movable part, is a ring of the bulging form seen in section at *d*, and shuts down at once on both these seats. If they be equal, therefore, it may be lifted by whatever will lift its mere weight, the pressures of steam above and below the protuberant surface destroying each other; and if the lower seat be larger, as here shown, only the excess of its area over that of the upper measures the pressure effective in keeping it shut. A bar across the top receives the rod by which it is lifted (passing through a stuffing box), and when lifted it admits the steam by the two ways shown by the arrows, so that a steamway, equal to a pipe of a foot or more in diameter, may be opened in a moment, by hand, even for steam of the highest pressures.

It would be impossible to explain, without great space and numerous figures, the gear by which the three of these valves necessary to act at each stroke, as described in reference to Fig. 2043, are opened and

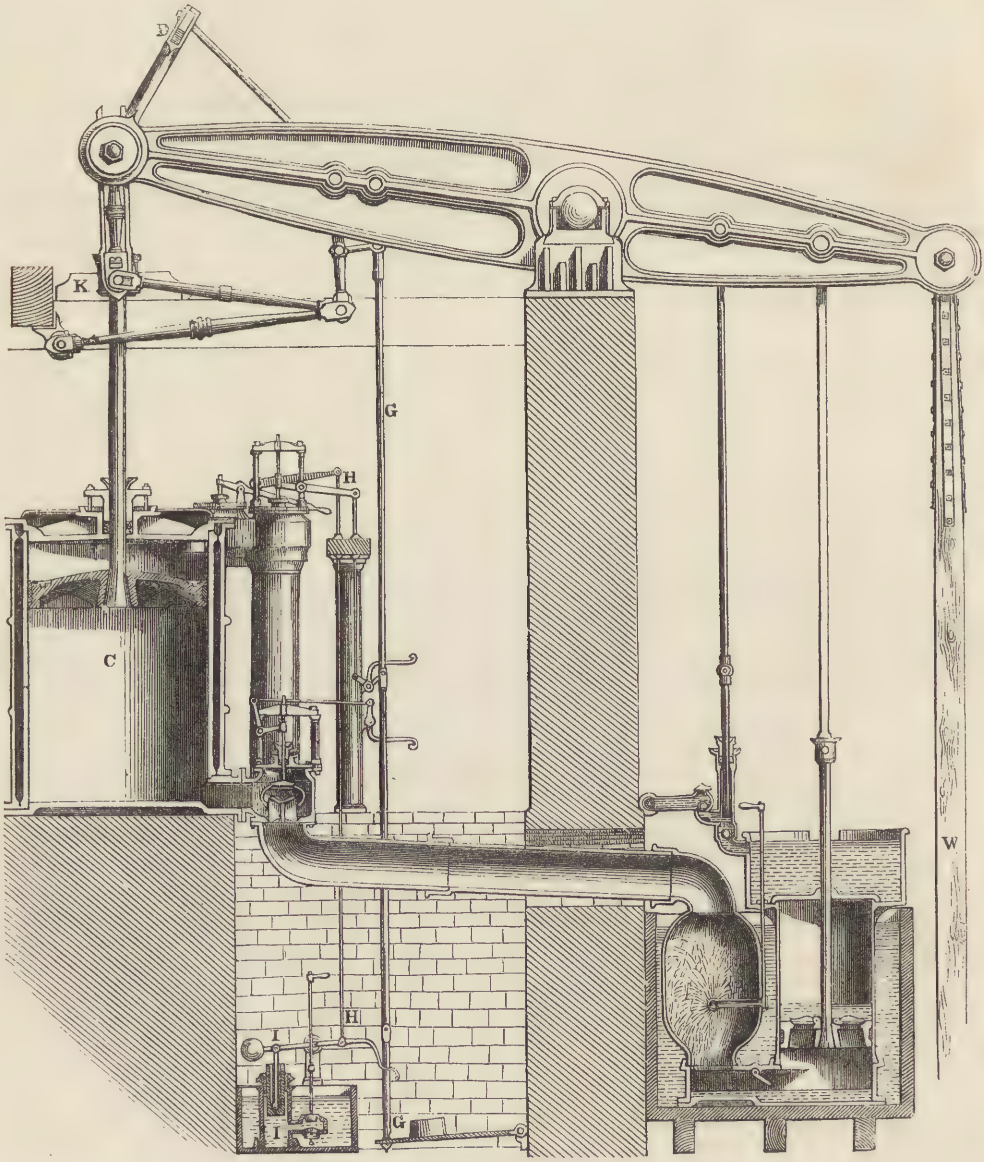


Fig. 2053. CORNISH OR SINGLE-ACTING PUMPING ENGINE.

shut in the Cornish engines, by the various *tappets* or projections from the suspended rod G, successively acting on levers of different forms projecting from three horizontal arbors, one of which governs each valve. It is a general principle, however, that the *opening* of each, which is what most calls for instantaneous motion, is effected not by the engine, but by a weight heavier than the valve, pulling the other end of the lever that raises it, and which the engine only *releases* by removing a catch. The shutting, in which suddenness is not so important, is effected directly by the motion of the rod G, lifting these weights again; and the shutting of the exhaustion valve is often, and the opening of the steam valve for a new stroke always, done by the separate rod H, that ascends from and is moved by the cataract I as before explained, this answering the same end as the governor in rotative engines.

The tappet that shuts the steam-valve, admits of being placed higher or lower on the rod G, so that the time for which steam is admitted, before it is left to expand, may be adjusted to the amount of work that is to be performed per stroke. In some cases only a twelfth of the cylinder is thus filled, (so far is the principle of expansion carried,) and as the pressure of the quantity thus admitted cannot be always identical, the depth to which the piston descends before being brought to rest by the resistances and load at W, balancing the decreasing pressure of the steam, is not constant; and to prevent its ever striking the bottom of the cylinder, there is an addition to the top of the beam bearing a cross piece of elastic wood D, which in too long a stroke strikes with its ends on the *spring-beams* or *spring-blocks* K without a violent shock. The speed of the piston in its descent is first quickly accelerated during the admission of the steam, then gradually declines as it expands, and thus ceases and is reversed; and, in its ascent, continually increases by the constant force of the load at W; so that the whole motion is *inversely* like that of a shot fired directly upwards, which is accelerated until it leaves the mouth of the gun, then gradually retarded till it is reversed, and continually accelerated again till it reach the ground. The danger of a violent shock at last, therefore, which might perhaps carry away the lid from the cylinder, is met by shutting the equilibrium valve soon enough to retain a "cushion" of steam above the piston.

In these respects rotative engines have a great advantage over single-acting, the crank not only totally preventing all chance of the piston striking either end of the cylinder, which is made long enough to leave a *clearance* at each end, but also obliging a gradual change of motion from each stroke to the next, like that of a pendulum, or of the shot abovementioned, when at the top of its flight. The chief danger to them is the accumulation of a layer of water in the cylinder, from either cloud or spray raised in the turbulence of the boiling, and carried by the steam into the cylinder, which is technically called *priming*. Water being compressed no more by 22,000 atmospheres, than steam or air is by *one*, of course a layer of it exceeding the space allowed for clearance in the cylinder, is equivalent to an equal mass of iron suddenly introduced, or the shortening of the cylinder by so much, and must immediately break whatever part of the engine is weakest.

We may here notice that modes of imitating the suddenness and nice timing of the Cornish valve motions, with machinery of constant contact, have been devised, though not much used in England, in the smaller engines at least. With the common excentric, very little can be done in this direction, because the reciprocating motion which it communicates to its rod, and thence to all the succeeding parts, and the valves themselves, is evidently one of just the same kind as the crank obliges the piston to follow with such advantage, namely swiftest in the middle of the stroke, retarded to the point at which it is reversed, and not resting an instant, but turning back like a pendulum. It is this *not resting* which makes it objectionable as a mover of valves, in which is wanted, if possible, an *intermitted* motion, a rapid change from one position to the other, yet begun and ended without a shock, and then a rest in that position during a considerable part of the stroke. Certainly something equivalent to such a rest may be obtained by so forming one or more of the ports, that the slide in travelling across it may leave an equal and maximum width of steam-way open for a certain time. Thus, Fig. 2054 represents the section of the three ports as sometimes made on the side of a cylinder, the two leading to its two ends, and the intermediate and much wider one turning away to the condenser; and of the slide which is moved up and down across their mouths by its rod passing out of the valve-box (not here shown) by a stuffing-box. The slide is hollowed in the form of a box itself, and with such an aperture, that its lap or margin may just cover one port of the cylinder before the opposite margin begins to uncover the other, so that at

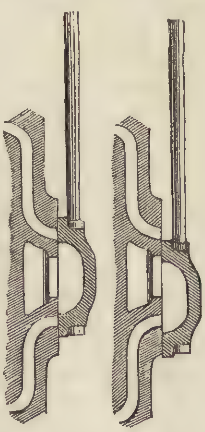


Fig. 2054.

the centre of its stroke both are stopped, as at A, and no steam enters either end. But owing to the narrowness of these ports in the direction they are here cut, (not in the other,) it very quickly opens to its interior the whole of one, and to its exterior the whole of the other, as at B; and however far it travel beyond this position, their whole mouths remain in communication, the one with its inside, *i.e.* with the condenser, and the other with the enclosing valve-box, *i.e.* with the boiler, and during all this time the effect is as if the slide were at rest. The middle or condenser port may seem to require an excessive width to produce this effect, as it might otherwise be itself narrowed to less than theirs, at the

extreme position of the slide; but in fact, both this and the whole pipe to the condenser should always be more capacious than the other passages, because the less elastic rare vapour travels less rapidly, in proportion.

But it is not possible in this way to carry the expansion principle beyond a very limited extent. For this a more interrupted motion is absolutely necessary, and that cannot be had from the common or *circular* excentric. Hence excentrics have been made in other shapes, as that in Fig. 2055, which is meant

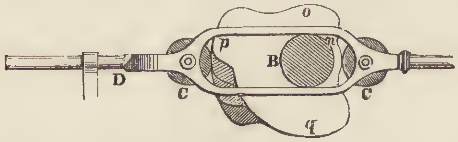


Fig. 2055.

to move the slide shown in 4 positions in Fig. 2056. Of these, N is the position for beginning

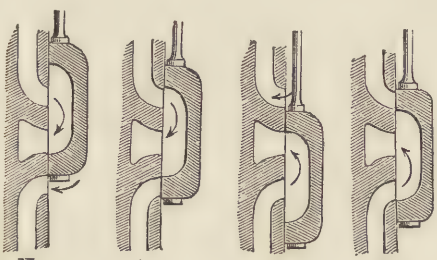


Fig. 2056.

the up-stroke, the steam freely entering the lower port and issuing from the upper into the middle or condenser port. O is the position for the latter part of the same stroke, the eduction continuing as before, but the access to the lower port being stopped, that the steam below the piston may drive it up the rest of the way by expansion. P is the position for beginning the down-stroke, being the converse of N, and Q the converse of O, for finishing it. Now the excentric, Fig. 2055, has its outline formed of 4 circular arcs, *n*, *o*, *p*, *q*, all described from the centre of the axle B, but with different radii, and connected by sweeps to avoid sudden shocks. The diameter, however, taken in any direction through the centre of the axle, must be equal to the distance between the 2 friction wheels C C, which turn like sheaves of a pulley between 2 oblong frames (one of which here hides the other), and from their united ends proceeds the rod D that carries the motion to the valve-gear. Thus the revolution of this excentric puts the rod into 4 different positions, and keeps it some time in each. The ratio between the time of passage, or angular extent, of the arc *n*, and that of *o* (which must always be the same as between *p* and *q*) determines how much of the cylinder shall be filled by influx compared with the space filled by expansion, or what is technically called the *grade* of expansion. Often, therefore, the means of changing this is provided, by making the excentric thick enough to be shaped as though composed of several (in this case 4) excentrics, laid one on another, the sweeps from *q* to *n*, and from *o* to *p* coinciding in all, but that from *n* to *o* occurring a step later in each, as also that from *p* to *q* (the former cannot be seen, it being on the other side). Then, by slipping the frame and friction-wheels to or from the spectator, it may be made to receive the action of any one of these different forms of excentric, according to the greater or less load on the engine, and less or greater advantage to be taken of expansion.

Such forms are not commonly called excentrics, but the projections on them *cams*, in this case *expansion cams.*

Artificial circumstances arising out of legal and commercial anomalies, occupations dependent on fashion and caprice, on the over-growth of towns, &c., may evidently cause (even in stationary engines), the naturally paramount objects of fuel-economy, durability and safety, to be outweighed and become secondary to others, as economy of space, of water, of particular constructive materials, of particular kinds of workmanship, &c.; and hence give birth to various minor or accidental forms of engine, besides the two natural or standard kinds above described. Of these the chief, (besides the land and water *locomotives,* which we reserve until last,) are, I. the *double-cylinder;* II. the *rotary-disc;* and III. the *high-pressure,* more properly called the *non-condensing engine.*

I. No sooner had Watt proved the great increase of duty to be obtained by the expansion principle, than the apparent inconvenience of the continual diminution of the moving power during the expansion, (though it really tends to equalize the motion, which would otherwise, with an uniform power, as in the return stroke of the Cornish engine, go on with acceleration,) led various inventors to contrive engines in which the steam, after filling one cylinder by its full pressure, should be allowed to proceed from that into a larger one by expansion only. Hornblower seems to have been the first to introduce the plan, although a double-acting engine of this kind is now known as a Woolf's engine.

In the form given to it by Messrs. Hick & Bolton, the two cylinders, which have their capacities in the ratio of 1 to 4, (namely, their diameters as 23 to 40, and their lengths as 3 to 4,) stand side by side, the larger under the extreme end of the beam, and the smaller a fourth nearer its fulcrum, so that one jointed parallelogram for parallel motion serves to receive at different points the heads of both their piston-rods, which are thus obliged to rise and fall together. The small cylinder has its *valve-box*, that is to say, a contrivance such as above described in Figs. 2054 and 2056, the two ports to the top and bottom of the cylinder being lengthened passages attached to it, or formed in a projection cast in one piece with it, and coming nearly together in the centre of its height. This wastes at each stroke the quantity of steam contained in one of these passages, but is now generally adopted in all but the largest engines, to save the material of a long steam-chest and slide, these being reduced to such a length as merely contains the two apertures or entrances to these ports,

and the third opening between them, leading away laterally to the condenser. From the valve-box of the smaller cylinder, however, of this form of engine, this passage of exit leads only to the steam-chest of the larger, or rather to one of two upright tubes standing beside it, both of which tubes communicate with the top and bottom thereof by double-seat valves. Entering and filling the first of these tubes, it finds the valve at that end, which answers to the end of the small cylinder it has just left, shut, but the contrary one (answering to that at which the small cylinder is receiving steam) open, and thus it drives the large piston in the same direction that the small one is being driven at the same time by fresh steam from the boiler. Meanwhile, the steam on the other side of the large piston, which has successively filled both cylinders, and is four times rarer than it was in the small cylinder, is passing into the second vertical tube, whose foot leads straight to the condenser. Thus the sliding-valve, and the more perfect or Cornish mode of directing the steam, are both used in this engine, the former for its first admission into the small cylinder, and the latter for its future progress when less elastic, and therefore requiring larger steam-ways to pass through in the time allowed, and more instantaneous and well-timed opening and shutting. The gear acting on both the slide and the four double-seat valves, however, is moved by an excentric on the axle, as in Fig. 2044, and therefore is gear of *constant contact* throughout, nothing *catching*, or *touching*, and *leaving* another, as in the Cornish gear.

II. *Rotary* engines, of which almost innumerable forms have been patented and abandoned, are those in which the steam gives uninterrupted (and therefore of course rotary) motion to the very surface or surfaces on which it presses. These engines originated in the erroneous but prevalent notion before alluded to, that motive power may be lost or diminished in any other way than by friction, shocks against imperfectly elastic matter, fluid resistance, or by doing useless work, (which indeed includes both the latter.) Of course, the average resistance which a crank could overcome all round its circuit, is less than the piston-rod could throughout its double stroke, but only in the ratio that its average velocity is greater, the path described in the same time being longer as 3·1416 to 2, the circumference of a circle to twice its diameter. The greater distance travelled just compensates for the diminished load moved, as in all such cases. But this is no loss of motive power, any more than it is a loss for the muscles of our upper arm to pull the fore arm close to its fulcrum, the elbow, with an immensely harder pull than we can exert at the hand, where the resistance is commonly met, for we move the hand through a space just in that same proportion larger than the muscles contract through. Is it expected that a piston only able to lift directly, say 100 lbs. 2 feet in a second, is by means of the crank to lift the same 100 lbs. 3·1416 feet in a second? But some ask, is there not serviceable *momentum* lost in stopping and reversing the motion every few seconds? Certainly, if the motion be *stopped*, instead of *stopping itself*, which is what it ought to do in every engine; otherwise there is a *blow* or *shock*, which, against imperfectly elastic bodies, will indeed involve loss of power. But the fact is, that while the reciprocating piston *may* change its motion without any shock, or anything equivalent to it, the rotary one cannot do so. For, in the first place, just as much momentum must be reversed in the revolution as in the double stroke. A revolving body must at one time be moving northward, at another southward. Therefore it must, in half a turn, lose all its northward velocity, as surely as the reciprocating body must. Now the latter may lose it as an arrow shot straight upward, or the descending Cornish piston does, viz. by the resistance of the load only, (besides necessary friction,) the *work to be done*,—the water to be raised. (The Cornish piston is merely *jerked* down, and left to spend its impulse and rise again.) But whatever the rotating body loses, must be by a resistance foreign to the work done, viz. by the resistance necessary to confine it to the centre, or restrain what we call the centrifugal force; for that is the name given to the momentum thus destroyed continually throughout the revolution, and which altogether is just as much as the piston would lose if striking suddenly against both ends of the cylinder; changing its motion not as a pendulum or Cornish piston, nor even as the clapper of a bell, but as an electrical dancing figure, urged with unchecked acceleration till it strikes each plate. Whatever would be lost by these shocks, must *always* be lost during the revolution, in the shape of that continued accumulation of atomic shocks which we call friction: an addition by centrifugal force to the necessary friction, whether of an axle, or an enclosing case.

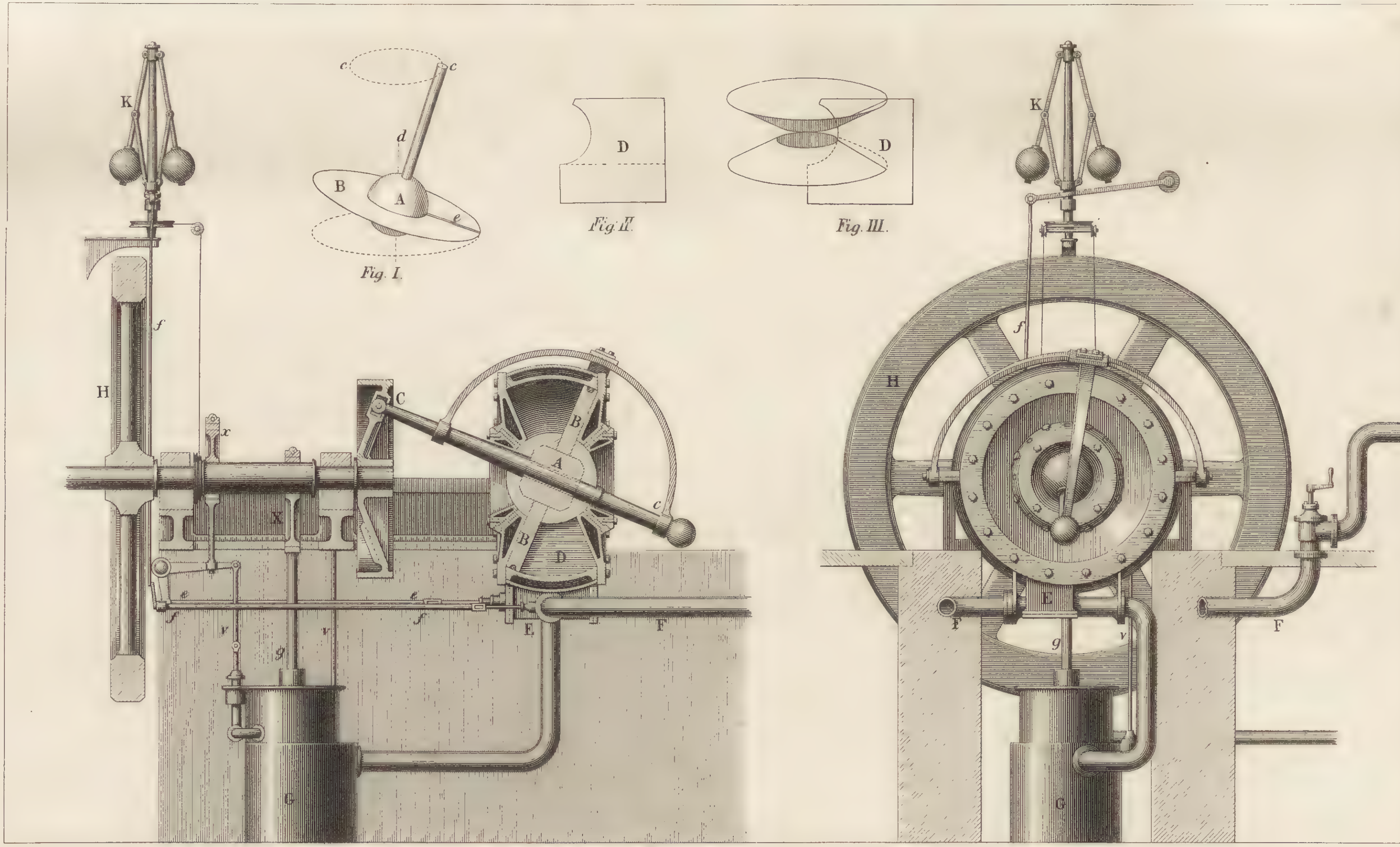
Besides all this, it is easily proved that while the fit of an ordinary cylinder and piston constantly improves by wear, that of every possible rotary arrangement must as constantly deteriorate; for the various parts of the same rubbing surfaces move with different velocities, whence it is impossible for them to wear equally. They must wear open at the parts furthest from the centre.

The extreme economy of space, however, in one rotary engine, *Bishopp's Disc Engine*, (represented in a steel engraving,) has brought it into some use in densely populated towns. In order to understand its action, let us imagine a ball A, (Fig. I.) into which the cylindrical rod *c* is inserted so as not to shake laterally. Let the ball be in two halves, between which the disc of card B is firmly held at right angles to the rod A *c*. If its top *c* be carried round the circle *c c*, while the ball constantly occupies the same place, the planes, successively assumed by B will change, as if the whole revolved round the imaginary axis *d*. But to resemble the motion of Bishopp's disc, there must be no such actual rotation of the ball and disc, but only of the point *c;* and such a motion of the disc as to make its plane vary and take all the positions of one thus rotating round the axis *d*. Its matter does not revolve, though the space filled by it does; and to imitate this, we must keep the same points of its circumference

towards the same points of the compass, notwithstanding the revolution of *c*. Cut a slit *e* along one radius of the disc, and insert therein the piece of card D, Fig. II., having its concave edge cut to fit exactly the ball A; and fix D vertically in one position by inserting it, up to the dotted line, between two leaves of a table. Now if the slit *e* be wide enough to slide freely up and down D, and allow the disc to incline itself considerably to the plane of D, we may carry *c* round the circle *c c*, keeping the ball always pressed into the concavity of D, or always filling one position in space, and the disc B will fill the same positions as if it revolved round *d;* every point of its edge becoming successively the highest, and (after half a revolution of *c*) the lowest, although it always keeps the same distance from the fixed partition D, and only moves up and down like each point in a cord along which waves are travelling, or each particle of matter in a real wave. Now, in order to see how the steam imparts this motion, we have only to add two conical surfaces, above and below the disc, as in Fig. III. such that were they complete cones, their points would meet in the centre of the ball A; to fit the surface of which they are truncated, and they may be kept steady by intersecting the plane D. If their inclinations be just equal, it is evident that the disc may be kept in contact with both, one whole radius touching one cone, and the whole of the opposite radius the other cone, perpetually, as *c* revolves. These cones form the two ends or faces of the chamber of the engine, (or *cylinder* as it is commonly called, from the habit of referring everything to the old form of engine,) and its remaining enclosure must evidently, to fit the edges of the disc in all its positions, be a spherical zone; but this need not be added in order to understand the action. The whole chamber is of course always divided equally into two parts by the disc, and in the two positions where the radius *e* touches either cone, the half on one side the disc (as, in Fig. III. that *below* it) is left entire, while that on its other side (in Fig. III. that *above* it) is again divided equally by the fixed partition D, into two quarters of the whole capacity of the zone, although they each occupy *half* its circumference, (as the undivided half does a *whole* circumference, except the thickness of D.) At this moment one of these equal spaces above the disc is in the middle of its connexion with the condenser; and in the other, the steam, just disconnected from the boiler, is exerting its expansive power to wedge apart the disc from the cone above, *i.e.* to remove their radius of contact further on, and extend itself from half into the whole circumference, when it will occupy the greatest space which it ever can do, viz. half the zone. And the other space above the disc, (for we are speaking now of what takes place on *one* of its sides only,) the other space will have been reduced to nothing, the touching radius which bounded it behind, having advanced round half a circumference and come to the slit *e*, which is now at the top of the partition D, instead of the bottom. At this instant, then, the whole space above the disc is undivided and full of steam, which at the same moment finds a way opened to the condenser; while the touching radius, advancing *past* the partition D, leaves between itself and that partition a small new wedge-like space, into which the steam from the boiler is admitted, and which it speedily enlarges; and when cut off from the boiler, continues to enlarge by its own expansion, as already described; the half filling of this and half emptying of the other space bringing us, by another half-revolution of the touching radius, (and consequently of the end of *c*,) round to the position of Fig. III. from which we started. It will thus be evident that the ports for inlet and outlet of the steam, on this side only of the disc, are placed close to the partition D, one before, and one behind it, that the latter may be constantly open to the condenser, as the former would be to the boiler, were there no expansive working, (which may be carried perhaps more easily to a great extent in this than in any other form of engine,) and that, unlike the single side of an ordinary piston, which is alternately *all* pressed by steam, and *all* left unpressed by its removal, a single side of the disc is only at two moments of the revolution thus exposed wholly to pressure or wholly to exhaustion, and at all other times varying portions of its area to each. All this, of course, takes place exactly the same on the other side the disc, half a revolution earlier or later, the space on that side being just filled, and replacement by fresh steam just commencing, when the space on this side is divided in halves, one in the middle of enlarging, and the other of being exhausted; so that the utmost moving power derivable on one side occurs when the other is powerless; the arrival of the touching radius at the partition D, (or of the slit *e* at the top or bottom of its stroke,) being a momentary interruption to the action of *one* side only of the piston, whose two sides act independently. And as the surface not pressed on one side the disc equals at every moment what is pressed on the other, the whole area pressed is constantly the same, viz. half the sum of the disc's two faces; so that the motion and power would be perfectly uniform were the pressure of steam so, or were there no expansive working; and the only inequalities arise from its diminished pressure when expanding.

Thus it happens, that a fly-wheel, not 1-third the size of that required by a common engine of equal power, suffices for this admirably compact contrivance; and the connexion with it being not necessarily more than a simple application of the end of C to one of its spokes, without beam, parallel motion, or crank-rod, the whole is easily compressed, when necessary, into even less compass than the engine here represented.

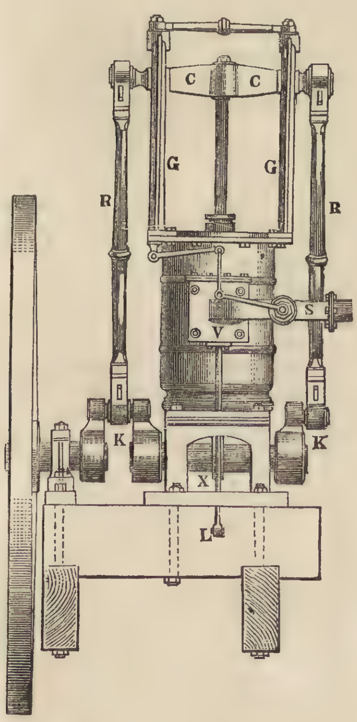
The zone, or working chamber, is commonly, as here, fixed upright or with its axis horizontal, and the disc-rod C *c*, which is fixed firmly through the globe A, has 2 semicircles passing over the chamber to help to steady its motion, which it communicates to a wheel by its end C turning in a socket or kind of universal joint. This wheel is on one end of the axle, which bears also the fly-wheel H, and the two excentrics X *x*, the larger for working by the rod *g*, the air-pump

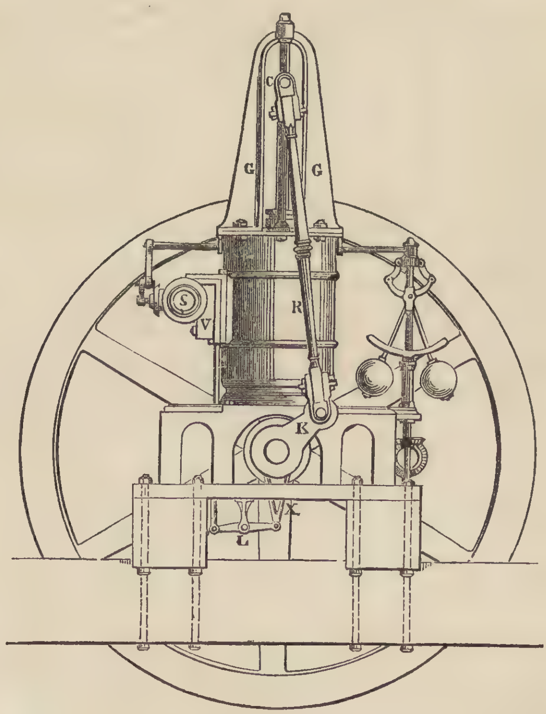


BISHOFF'S ROTARY STEAM ENGINE OR DISC ENGINE

standing in the condenser G, while the smaller performs the less forcible reciprocating motions, including those of the slide-valves in the box E, by two arms from an arbor changing the vertical motion of V into the horizontal one of *e e* the valve-rod. The governor K regulates by the rods *f f* the throttle-valve in the main steam-pipe F, all these details being as in other engines. Perhaps the air-pump may eventually become a miniature of the disc chamber itself, and its principle be extended to pumps even for other purposes; but the great obstacle both to this and the use of the engine, will be the extreme accuracy of fitting required by the working parts, even if they can be made to retain this accuracy for any length of time. The circumference of the disc B B is of course made to fit the zone by piston-rings, and presents no more difficulty than the ordinary piston. Against the stuffing-box of the ordinary engine (the simplest possible mode by which the motion generated within a steam-tight space can be conveyed out of it), we here have to set the two concave surfaces in which the globe A works; and there still remain all the nicest and most difficult adjustments of the disc, wholly additional to those common to all engines. The joints abovementioned, like that round a common piston, separate steam from rarer steam or vacuum by a contact of considerable breadth, as broad indeed as it may be desired to make it, and commonly as broad as the piston is thick. But in the two radii of contact between the disc and the cones, a mere *line* has to separate steam from vacuum, and as every radius successively forms this line, the whole of each of the four surfaces requires extreme accuracy. Again, the two contacts of the slit *e* with the partition D, must equally be reduced to linear ones, by either sharp-edged or rounded linings to the 2 sides of the slit, and pressed to the partition by springs, for otherwise the disc could not assume, as it must, different inclinations to the partition. Now in order that all these linear contacts may be steam-tight, an amount of accuracy is required which has not been obtained until very lately, and this will limit the use of an engine which depends on such high finish. Their friction, too, must absorb much power, and more than counteract the saving thereof in the edges of the piston by their moving through so much less space than the steam.

III. What are called *high-pressure* engines consist of merely the absolutely necessary parts of an engine, divested of all those contrivances which it can possibly do without, and which add to the first cost. They are the exact reverse of the Cornish engines (although both species make use of the highest pressures), economy of fuel being here made entirely secondary to that of construction. The condenser and its appendages are therefore omitted; and all the power obtainable from the *vacuum-forming* property of steam, amounting, we have seen, in the gross, to 1,700 cubic feet of water (*i. e.* about 10,500 lbs. avoidupois) lifted 33 feet high by the evaporation of 1 cubic foot, requiring 5 lbs. of coal—all this is dispensed with; the eduction passage leading not to a condenser, but





Figs. 2057, 2058 ELEVATIONS OF HIGH-PRESSURE ENGINE.

merely to the open air, as in Leupold's engine, Fig. 2040; so that the piston is pressed on the side of the issuing steam by the common atmospheric pressure of 15 lbs. per square inch, which (instead of the 1 lb. or so exerted by the cool vapour of the condenser in other engines) must be deducted from the pressure of the entering steam in order to find that pressure which is effective in driving the piston. This, the simplest possible steam-engine, is in fact but a *double-acting cannon*, a cannon of which the ball, or *piston*, is driven alternately from end to end by a body, more elastic than the air, alternately introduced at each end, both ends being closed and furnished with touch-holes; but the vapour is produced outside, and admitted through these, *i. e.* the coal is burnt outside the gun instead of within it; water is substituted for saltpetre; and (last, not least,) as the object, production is substituted for destruction.

There being no reciprocating motion to communicate except that of the valves, and of the feed-pump, if any, no beam and no parallel motion is used in these non-condensing engines. The piston-rod head is kept to its straight-lined course by sliding, with or without friction-wheels, along straight iron guides, of which there are usually 4, which (unless the cylinder be for some peculiar purpose placed in some other position than vertically) stand upon and are bolted to its lid, as at G G, Figs. 2057, 2058. From the ends of the cross-head, C C, descend the 2 crank-rods R R, to 2 cranks K K, on the fly-wheel axle, which passes under the cylinder,—and an excentric on this may work the slide of the valve-box immediately over it, although a more indirect gear is generally found convenient. In the figure, an excentric under the cylinder lifts and depresses by the short excentric rod X, the lever L, whose other end moves the valve-rod ascending vertically to V. The chain of levers from the governor to the throttle or regulating valve at S will also be understood by inspection.

Expansion cannot be carried nearly so far in these engines as in others, because, in order to take the same advantage of it, the steam can at the end be reduced only as near to the atmospheric pressure, or 15 lbs., as that of condensing engines may approach to the condenser pressure, or about 1 lb. Let us suppose the excess, or the effective pressure left at the end of the stroke, to be in each case 5 lbs. Then the final elasticity of the steam is in one case 20, in the other only 6 lbs., and to take advantage equally of expansion, the steam must originally have a pressure higher in the non-condensing than the condensing engine, as 20 to 6. Or let the final effective pressure be 1 lb., then the final elasticities of the steam are in one case 2 lbs., in the other 16; and steam of *eight* times more pressure must be generated in the one boiler than in the other, in order that it may economise to the same extent.

Steam-Boilers, which, although necessary to the generation of the power, are quite independent of the *engine*, properly so called, have assumed the following chief forms for stationary engines. Passing over the alchymist's *globes*, and Newcomen's *haystack* boilers, as founded on no accurate observation of the subject, and carrying out no true principle, (except perhaps that of avoiding upright sides, for a reason to be presently explained,) we find Smeaton to have first recognised the economy of enclosing the fire wholly within the mass of the water. We ventured to express our opinion that when Watt made an alteration in this arrangement, he retrograded somewhat in omitting the internal furnace, but he introduced what is called the *wagon* boiler, the earliest that still continues in use. As first made, this was of the exact shape of a wagon and tilt, *i. e.* a long parallelopiped finished above by a half cylinder; the whole of the bottom, the ends, and the sides up to where the cylindrical bending commences, being flat and at right angles. Now, both water, air, and gases being most imperfect *conductors* of heat, *i. e.* hardly permeated by it *while at rest*, although readily moved by it if unequally distributed, provided a warmer portion be beneath a cooler, so that their density may cause them to change places, the heating must be almost wholly effected in this latter way. A flat bottom, then, exposed to the fire, is the very best kind of surface for exciting such movements; and every surface so inclined, as to lean over the fire, or have the heating air and gases *below* every point, and the water *above* every point of it, will be, however little inclined from verticality, almost as good as the horizontal one, each point continually sending up the particle of water heated by it, and receiving a cooler in its place; or, while boiling, sending up its small bubble of steam, and receiving an equal bulk of water. But when the wall is *quite* vertical, the case is wholly altered. The air and gases on one side, and the water on the other, may each circulate independently, and almost without communication of heat, since nothing is stopped or diverted by either surface; whereas when it is inclined, the descending coolest particles of water are constantly falling upon the inner face, and the hottest ones of air and gas rising and striking against the outer.

In order to gain more surface than that afforded by the bottom only of these wagon-boilers, Watt afterwards hollowed their sides, as in Fig. 2059, (the cross section of one of his most improved boilers), so as to make the upper half, or a little more, of each, to lean over the flues A B, and although their lower half would seem to be even less effective than an upright surface, it is hardly any loss, as the steam produced by either is almost nothing. He also hollowed the bottom, apparently to resist the pressure, on the principle of the arch; since any flat surface in boilers evidently tends by the pressure to bulge outwards, equal areas of surface giving room to more and more bulk of contents as they approach nearer to sphericity. But, by making any surface convex inwards, it will be secure against outward approach to flatness if the ends of the curve be kept from moving further apart, either by abutments of masonry, or by being tied together. Thus, some bands passing round this boiler, and straight across the concavities of the sides and bottom like bowstrings, would obviate the necessity for any of the internal stays commonly applied, ex-

cept those used to hold the flat ends to each other, or to the sides. Indeed, only *flat* surfaces can create any

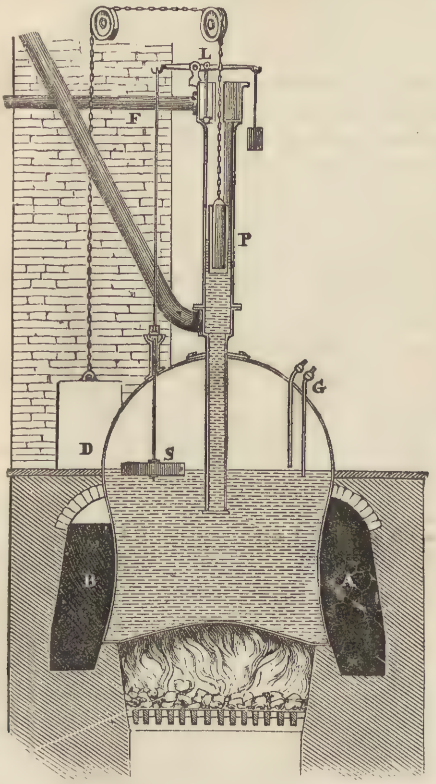


Fig. 2059. WATT'S WAGON-BOILER.

necessity for internal stays; *inwardly curved* ones admitting of being thus stayed externally, although the principle seems not to have been applied.

These boilers are so set, that the flame and smoke, passing from the grate under one end to the further end, then turns into one side flue A, and comes back to the front end, which it crosses by a flue above the fire door, across from A to B, and then along B to the chimney at the further end. The aperture of this is often regulated by a *self-acting damper, i. e.* a plate D, sliding in grooves, and suspended by a chain passing over two pulleys, and more than counterpoised by the weight seen within the *standing pipe* P. This pipe is that into which the boiler's supply is poured by the feed-pipe F, and (unless the steam's pressure be below that of the air, a very rare case indeed, because although condensing engines, when once started, could be kept going with such steam, the power obtained would be disproportionately below what the same cylinders are capable of,) the water in this pipe P must of course stand as high above that in the boiler, as to balance the excess of the steam's pressure above the air's, or about 33 feet if that excess be one atmosphere, 11 feet, if it be 5 lbs. per inch, &c. The counterpoise of the damper floats on this water; and hence, when the pressure increases, the rise of the water and float allows the damper to descend and diminish the draught through the fire, and consequently the consumption of fuel and the production of steam. When too little is formed, the pressure decreases, the water and float sink, the damper is drawn up, and the fire increases until equilibrium between the production and expenditure of steam is restored.

The regulation of the supply of water is the most important of all the wants of the engine, because its sinking too low may leave some portion of the boiler dry near enough to the flues to become much hotter than itself, and so, on being again covered by a fresh supply, evaporate it so rapidly as to endanger explosion; while too much water will obviously increase the risk of some being carried up with the steam (or *priming*, as it is called), and accumulating in the cylinder until it stop the piston short of a full stroke, and break down some part of the machinery. Thus the presence of too little water endangers the boiler, and that of too much, the engine; and hence the observation of its exact level must be made as easy and unerring as possible. A window, or rather loop-hole of thick glass, is the most perfect means, but has been little used, from the difficulty of keeping it cemented steam-tight. A piece of glass tube is more easily kept cemented into two brass sockets for its top and bottom, and these screwed into the boiler at a little distance above and below the proper level. But as some obstruction in these may prevent the level keeping always exactly the same in the tube as in the boiler, a second test is provided in the *gauge-cocks* G, which terminate two slender pipes, one descending to a little below, and the other to a little short of the proper level of the water, so that if on opening them, both yield water, or both steam, the level is known to require correction by stopping or increasing the supply.

Any self-acting apparatus for assisting in this duty has perhaps been justly condemned, as tending to a relaxation of the watch that, in any engine supplying (as all but toy steam-engines do) the place of several human hands, should be obliged by law to receive at least the undivided attention of one man. Such an apparatus, however, has been devised, and consists of, first, a partition across the standing pipe P near its top, with a smaller short tube ascending from a hole in its centre to allow the chain of the damper counterpoise to pass through, but form around it an annular cistern, in which the water, entering from the feed-pipe F is retained, except when a small valve in its bottom is lifted and allows some to fall through and supply the boiler. This valve hangs by a rod to the lever L, very near its fulcrum; and from the same end of this lever hangs a weight, while from its contrary end hangs by a wire, passing through an easy sort of stuffing-box, into the boiler, the float S, made of stone or metal, but so counterpoised as to float, and broad enough and heavy enough for its rising and sinking to overcome the friction of this stuffing-box, and thus lift or close the valve hanging from L, according as a supply is wanted at the moment or not.

The increased pressure, however, which must soon become universal in modern engines, evidently will render, if it have not already nearly rendered, the

mode of supply by the above standing pipe obsolete. For a height of 33 feet for every atmosphere (or 2 feet 2 inches for every pound) of pressure beyond that of the air, cannot be allowed this apparatus even with the present very general use of steam of 3 or 4 atmospheres, which we believe it will be found worth while yet greatly to exceed. The feed-pipe must therefore pass direct from the plunger-pump (see Fig. 2053) into the boiler. Now this, although it does not render a *mechanical* governor or regulator of the supply necessary nor desirable, yet renders mechanism for the regulation of it, by a *human* regulator, absolutely essential. For the feed-pump, left to itself, must introduce a precisely equal bulk of water at each stroke, but the quantity evaporated by each stroke, or even by each thousand strokes, cannot be made to preserve anything like equality, even with an engine doing the same work constantly. Every time the safety-valves were opened, the level would sink and then remain permanently lower; and every time the pressure were purposely raised or lowered, even without altering the grade of expansion, the quantity of water returned at each stroke must evidently be quite altered if the level is to be maintained. The simple expedient is a stop-cock of variable aperture in the pipe by which the feed-pump draws its supply from the hot well. This so reduces the aperture, when necessary, that there shall not be time, during one stroke, for a bulk of water, equal to the plunger, to pass through this aperture into the pump, in which, consequently, a vacuum will be left when the plunger is furthest withdrawn. The power spent in thus withdrawing it against the whole pressure of the atmosphere is obviously regained by that pressure aiding its return stroke.

The other essential appendages to all boilers are the *safety-valve*, the *pressure-gauge*, the simplest form of which is described under STEAM, and a *man-hole* for entering the boiler in order to repair it.

Watt sometimes added to the wagon-boiler a square flue, passing through the water from the end farthest from the fire, to the chimney at the fire end. The motive for its square form, especially as two sides were placed upright, is inconceivable. Such flues are now always of the shape most easily made, *i. e.* cylindrical, and generally large enough to receive the whole fire-grate and ash-pit in their mouth, thus reviving Smeaton's excellent principle of surrounding the fire with water in order that no heat may be spent on anything else directly; while retaining Watt's principle of lengthening the boiler so that it may take heat from the products of combustion for some time after they have been burnt. This arrangement, with the outer case also simplified to the easiest and probably best shape, a cylinder, forms what is now called the *Cornish-boiler*. It is set either on a central longitudinal wall, leaving 2 flues or air-casings to its sides, as in Fig. 2060, or 2 parallel walls, forming besides these a flue under the bottom. In both cases, the products of the fire pass first along a central flue, either through or under the boiler, then back through 1 or 2 others to the fire-end, the arrangement being called a *split* draught when it returns by 2 of them and finally along one in the same direction as at first, to the chimney.

Fig. 2060 represents the boiler as an *oval* cylinder

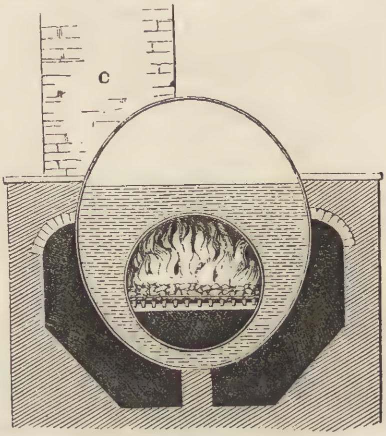


Fig. 2060. CORNISH BOILER.

with its longer axis vertical. This, although not a common arrangement, is far better than one often adopted with the same object; the object of keeping the water, and consequently the flue (which must always be preserved from the risk of having its top uncovered) lower, and so leaving more steam space than is attainable with both boiler and flue cylindrical. To this end it is usual to make the *flue* elliptical with its larger axle horizontal, but such a figure opposed to external pressure is most unsafe, and explosions by collapse of the flue are more destructive than others, in consequence of the fire and grate being blown out as from a piece of ordnance in the exact direction most certain to do mischief. All pipes exposed to external pressure should, unless provided with internal struts, be made as exactly cylindrical as possible, and the end proposed can be better attained as above, by an oval form in the boiler itself.

As even a perfect cylinder, whenever pressed from without, is in unstable equilibrium, every deviation from the circular form tending to *increase* until it collapses, the principle of using a broad elliptical flue, whose upper and lower sides are kept apart by vertical *tubular-struts*, allowing the water to circulate, is certainly a great advance. These short tubes should be conical that their sides may overhang the fire or hot air, and if we consider that all the steam generated in them has to leave their top, and need only be replaced by a thousandth or less of its bulk of water through their foot, they may evidently be made very conical with advantage. In Galloway's patent boiler on this principle, of which a cross section and a plan are represented in Figs. 2061, 2062, these tubes are admirably arranged, but only *slightly* conical. The two fire-grates are for the purpose of so feeding them alternately, that the smoke emitted by each, when newly fed, may be consumed by the other to some extent.[1]

(1) The details of the Cornish boiler, with Sylvester's fire-doors &c. used in the experiments on steam-coal, &c., are given in the article FUEL.

The proportionate length of boilers still varies from 2 to 6 times their breadth. The *best* proportion remains quite unknown, because, if discovered, it would evidently not be *patentable*, so that no private person will make the requisite experiments.

As *water* and *iron* are the materials which nature has provided for steam-engines, so is *copper* the material specially destined by its properties for boilers. It is very superior to any other on account of its almost harmless behaviour when destroyed by accidents, and it is also *cheaper* than the material which ranks next to it in economy, viz. *iron*, in at least the ratio of 2 to 1. By this we mean, that, in order to produce a given quantity of steam, at a given pressure, during a given period, (long enough at least to require one renewal of the material of the boiler,) in a copper boiler, and to do the same also in an iron one, the expenditure of iron, and the labour on it, will cost at least double the expenditure of copper and the labour on it. It would seem, therefore, that whatever might, by artificial anomalies, come to be commercially the material best worth being used for private interests, all boilers made by governments or permanent public bodies would necessarily be of copper. Such, however, is not the case in England, even in war-steamers, and it is not worth while, in this place, to inquire into the reasons why iron is the material preferred.

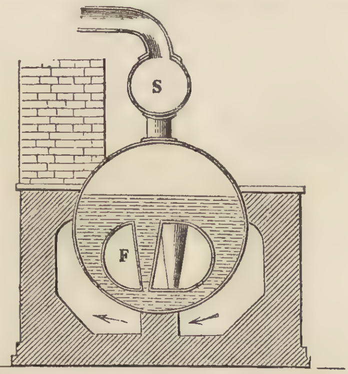


Fig. 2061. GALLOWAY'S BOILER. (*Cross Section.*)

The highest pressures are the safest to use, because every boiler must be made to bear, and be tested with, a pressure exceeding in a certain ratio the greatest which it is to be used with, or which the safety-valve is to be loaded with. For example:—let this ratio be 3 to 1; then the allowed pressure must be at least tripled before the boiler can burst. But this is far less likely to happen with a high pressure than with a low. It is far less likely that the pressure will suddenly increase from 3 atmospheres to 9 than from 1 to 3; far less likely that it will exceed the load of the valve by 90 lbs. than by 30 without opening it. Experience confirms this evident truism, the classes of engines using the highest pressures, viz. the *Cornish* and the *locomotive*, having led to the fewest explosions.

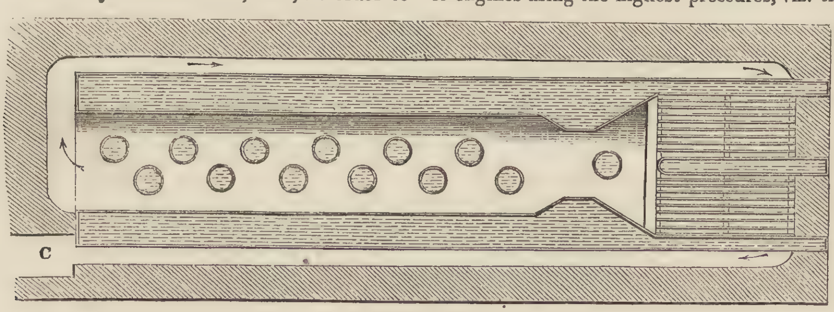


Fig. 2062. (*Plan.*)

It should be required by law, that every boiler be tested with air under the inspection of a public officer, and the maximum pressure be stamped or cut on some conspicuous part, (as is done at Birmingham in the case of gun barrels.) It should further be required that each boiler have two safety valves;—but the locking one of them up, out of reach of the attendants, is a very questionable proceeding, since the effect must be to relax their vigilance. The question is, does the added security of *one* such valve outweigh this? There is reason to think not, unless indeed a fine were exacted for every time the "lock-up valve" opens. It was long supposed that for very high pressures the safest preservatives were plugs of fusible alloys, in different parts of the boiler, composed so as to melt at the temperature corresponding to a pressure, say halfway between that stamped, and that with which the boiler was tested; but simple plugs are rendered worthless by the very curious fact noticed under BISMUTH, viz. that the plug of alloy, when exposed for a length of time to a temperature near its fusing point, undergoes a sort of eliquation by which a more fusible alloy is melted out, and that which remains is so much less fusible than the original alloy, that in some exploded boilers the safety plugs have been found entire. Enclosing the fusible metal in a *thin* coating of copper (such as an electrical deposit) might obviate this.

Locomotive engines. The first idea of a *locomotive machine* was a truly bold one. It was conceived and carried out early in the middle ages, in the form of various automata, some we are told even *flying*, by the power stored in the winding up of springs. The idea of a *travelling* locomotive (which might have been carried out in the same manner, had men directed their attention to locomotion by means of railways) dates, however, from a period since the general application of steam to nearly all other mechanical purposes, and has only

been put in practice with steam power directly acting and generated within the vehicle itself. That it would only succeed with the most perfectly prepared ways, or rather, guiding passages, might be anticipated, though many fruitless trials with self-guidance on the common English roads were at one period made. But in the mining districts of England railways both of wood and iron had long existed, and of these (except the most minor class) it took possession, and by its success, led to that enormous extension of such roads, in number, scale and unprecedented costliness of levelling, which has made the *railroad* and the *steam locomotive* now almost inseparable ideas. [See Roads and Railroads.]

In 1804, Richard Trevithick made and patented the first steam locomotive, which ran on a railway at Merthyr Tidvil. It is remarkable how nearly, after numerous changes, the newest have reapproached to its arrangement. The cylinder was laid horizontally below the front of the body or boiler, with its rod proceeding backward and continued by another rod, jointed to it, working the crank in the middle of an axle bearing a *fly-wheel* (necessary to all rotative and uncombined or single cylinder engines,) and on the same axle two cogged wheels, driving two others on the axle of the hinder supporting wheels; by whose resistance alone, against the rails, which were of iron, the engine was urged along; drawing 10 tons in addition to itself at the rate of 5 miles an hour. Seven years afterwards, under the notion that the resistance between smooth rails and tires could not be depended on to drive a carriage, *i.e.* that the wheels would slip round without advancing, a racked or toothed iron rail and driving wheel were patented, but failed from the enormous wear and tear. A chain lying along the centre of the road fixed at the ends and turning once round a grooved driving wheel, with teeth catching each link, by which the engine *ferried* itself along, was, as might be expected, still less successful; and was succeeded by a truly ingenious expedient, Brunton's jointed propellers, made to imitate, behind the carriage, the shape and action of the hind legs of a horse, alternately lifted from and applied to the ground by a very simple and frictionless arrangement of joints from *two* cylinders laid horizontally as in our modern locomotives. It was abandoned from a great accident occurring in an attempt to use it on a common road.

It was soon proved, however, that the weight of an engine must always press its wheels to the rails hard enough to ensure their advancing without slip, even when drawing a train of considerable weight besides. Still, to get the friction of four wheels instead of two, Stephenson's first locomotive had the two axles connected by an endless chain passing round toothed wheels, one on each. But he introduced the excellent and now indispensable principle of using two cylinders and pistons acting on cranks so situated, that when one is at what is technically called one of its two *dead points*, nearest to or farthest from the cylinder, and moving for an instant by the mere momentum of the revolving parts, the other shall be in the position that receives the fullest effect of the steam; or that when one piston is just turning from stroke to stroke, and for the instant powerless, the other shall always be at the middle of a stroke; each engine following the other at an interval of half a single stroke, (or keeping the position of the other's *slide valve,*) a principle now universal in both land and water locomotors, and by which the fly-wheel is dispensed with, because the joint motive power of the two engines together remains practically almost equal throughout a stroke. His cylinders were vertical and over the two axles, their cranks being kept in this necessary relation (viz. at right angles to each other) by the endless chain making the two keep time together.

The Stockton and Darlington iron railway, and some of those on the Newcastle coal-field, had long been travelled by various locomotives, when the Liverpool and Manchester railway company, having completed that line, vastly exceeding all former roads in amount of artificial levelling and high finish, offered a premium of 500*l.* for the production of the best locomotive, which, on the trial of four, in October 1829, was awarded to Mr. Stephenson's "Rocket," whose attainment of $12\frac{1}{2}$ miles an hour with thrice its own weight attached, and especially of 29 miles an hour when alone, excited the utmost admiration, and at once introduced the idea of railway *travelling* (such roads having previously been regarded as only for the carriage of goods) and excited that rage for speed of travelling which has led in the 20 succeeding years to the prodigious and incessant multiplication of levelled roads of hitherto unimagined levelness, cost and elaboration, for the sake of using similar engines, since that time about doubled in capabilities of speed, and trebled in compactness.

The one paramount requirement in a locomotive engine being *compactness* or the production of a maximum power in a minimum space, all other considerations give place to this. Hence no idea of carrying a condensing apparatus and supply of cooling water has ever been entertained, but the steam merely expelled from the cylinders into the air, as in high-pressure engines of the simplest kind, as already noticed under Fig. 2057, for neither can the principle of expansion be practised, since the power has to be obtained from the smallest *machinery* that will afford it, and not from the least *fuel;* or in other words, a given cylinder must yield its utmost *power,* even although this may involve the smallest *duty.* And the boiler being, as we have seen, the member whose power is most absolutely dependent on its size, and in a given bulk is limited by natural laws, it necessarily receives the chief attention, so that the problem resolves itself mainly into the contrivance of a boiler to evaporate the most possible water per minute or hour, in the least possible space; with how much fuel is quite a secondary consideration, since this can be carried in a separate vehicle, and its economy is a minor affair in fulfilling so purely artificial a want as that speed of transit on which the present railways and machines of this class depend.

The principle introduced by the "Rocket" boiler, which constituted the superiority of that engine, and, carried still further in all later ones, may be said to have *made* the present railway system, is that of

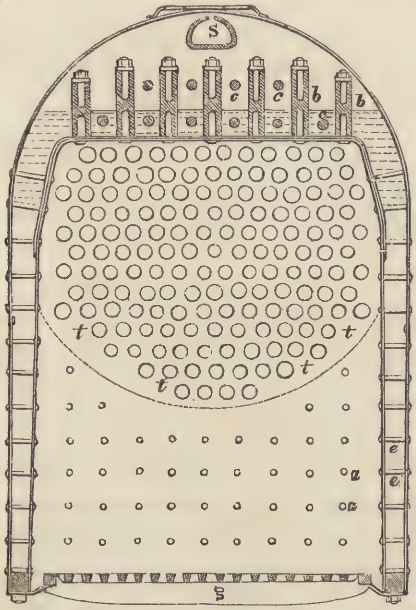


Fig. 2063. CROSS SECTION THROUGH THE FIRE-BOX OF CRAMPTON'S LOCOMOTIVE.

carrying the hot products of the fire through the water by numerous small parallel flues or rather tubes; thus dividing the heating matter, and, as it were, filtering it through that to be heated; immensely multiplying the surfaces by which they communicate, and at the same time bringing the heating and heated fluids nearer together, because the small diameter of these tubes enables them to be proportionally *thinner*, the pressure a cylinder will resist depending, not on its absolute thickness of solid wall, but on the proportion thereof to the whole diameter. Thus the water and heating gases are, by a sort of rude approach to the mechanism of an animal's lungs, minutely divided and presented to each other, like the air and the blood, at as many points, and with as little intervening matter as is consistent with their separation.

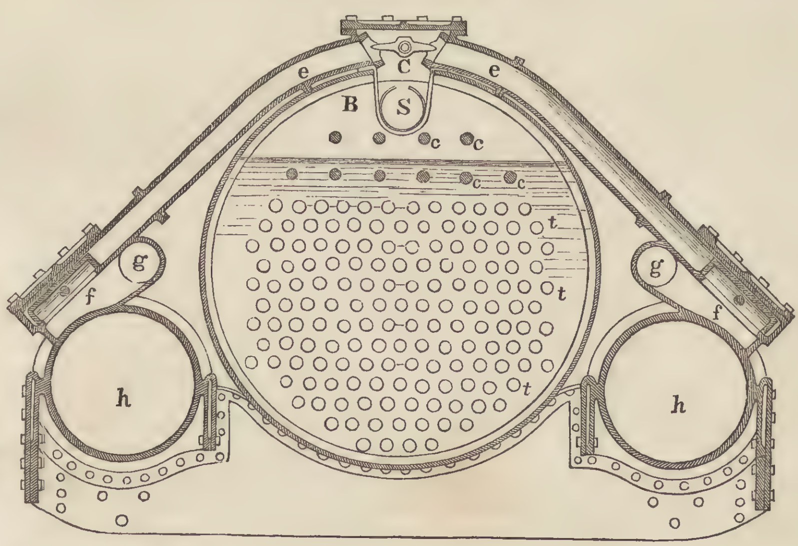


Fig. 2065. CROSS SECTION OF THE SAME THROUGH THE MIDDLE OF THE BOILER AND CYLINDERS.

The locomotive boiler now always consists of a cylindrical body laid horizontally, with flat and vertical ends, and a nearly cubical addition, of its own breadth, depending from the hinder end; *i.e.* we may consider the lower half of the cylinder, for a length nearly equal to its breadth, replaced by a cube,

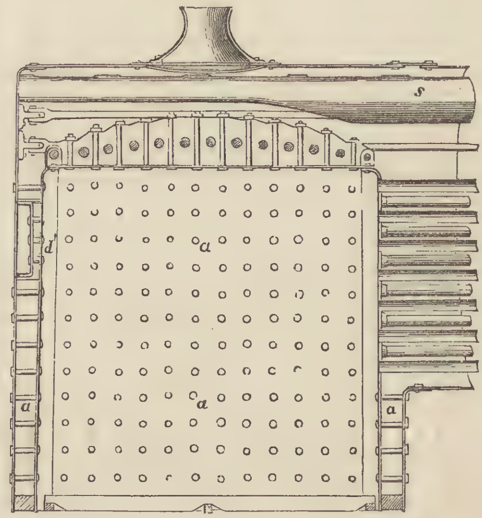


Fig. 2064. LONGITUDINAL SECTION OF THE SAME.

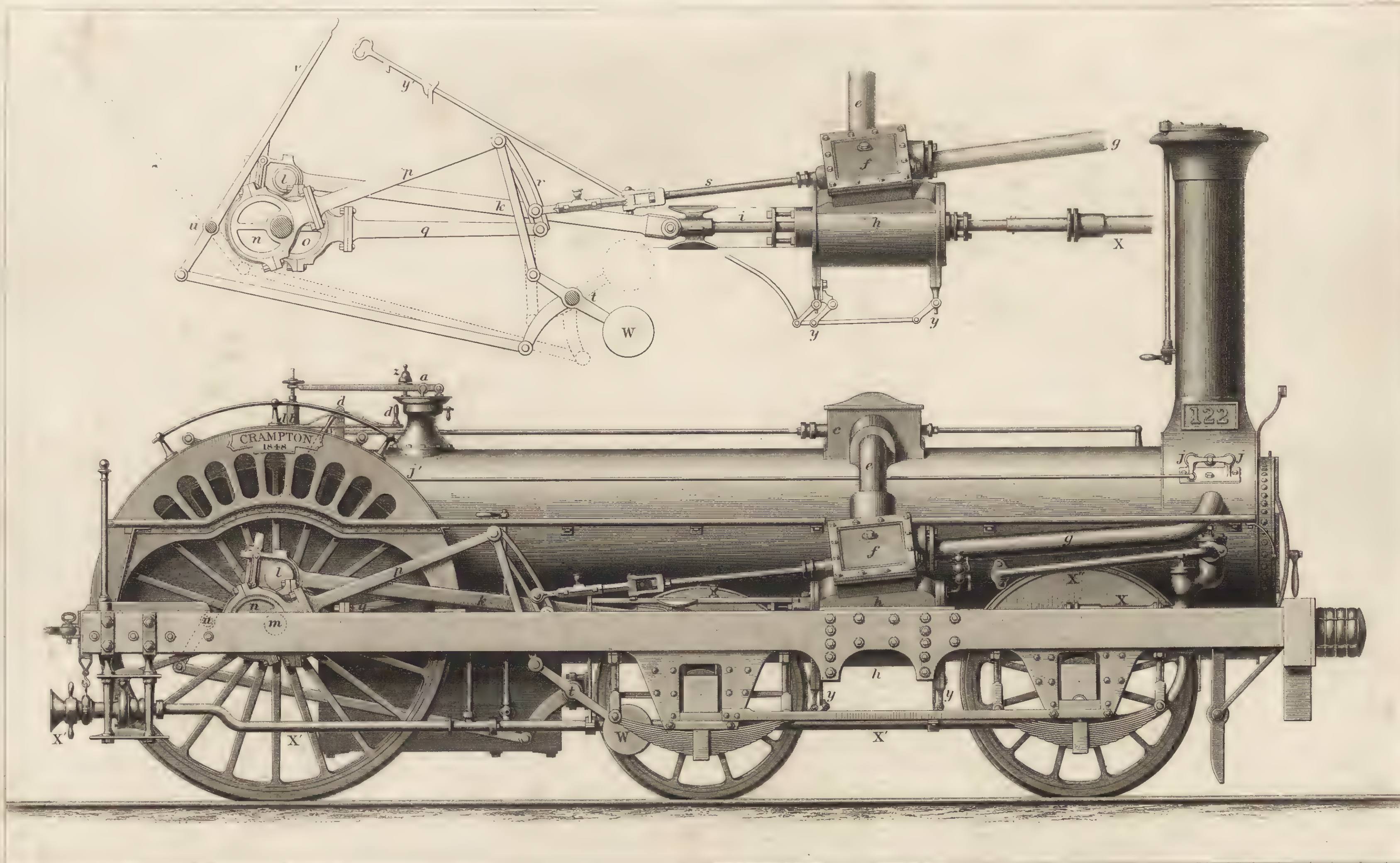
which of course hangs down about half its depth below the belly of the unaltered part of the cylinder. This cubical part encloses the fire-box, nearly filling it, and extending partly up into the semicylindrical arch above; and Figs. 2063 and 2064, represent the two vertical sections of this part in the fine engine of Messrs. Crampton's whose side elevation is given in a steel *engraving*. In Fig. 2063, it is cut by the middle plane of the locomotive, and in Fig. 2064, by a plane crossing it through the fire-box. Fig. 2065, is another cross section through the round part of the

boiler, about the middle of its length, and the same letters apply to all. The fire-box, it will be seen, is double walled, or rather walled and roofed with a layer of water, leaving only the bottom vacant which receives the grate bars *g*. In many engines a plate of iron descending from the back, or wall containing the fuel door *d'*, bends under this grate as an ash pan, and, by the sides also continuing down, encloses a lower chamber, open only in front, that the forward motion of the engine may oblige the air caught in this receiver to pass up through the fire and create more draught the more it is wanted. The two plates enclosing the water walls of this box are everywhere *quilted* together by the long rivets *a a*, &c., as the sides of a mattress by stitches. But a large portion of the forward face is not thus double, it being included in the cylinder of the boiler. This, then, is held from collapsing on the fire, by the numerous tubes above mentioned, *t t t*, &c., which are thus stays as well as flues, going straight through the length of the body of the boiler, and tying together its two flat ends so as to prevent it from bulging. But above the top of the fire-box other stays are wanted for this purpose, still longer. and these are furnished by the solid rods *c c c*, which proceed from end to end of the entire boiler, fire-box included. Lastly, the flat ceiling of the fire-box (which cannot be raised higher because it must be kept well covered with water) is sustained by bolts passing up through the deep cast-iron joists *b b b*, The mode of taking the steam from so moderate a steam-space as is left in the upper curve of this boiler, without admitting the fine spray or mist carried up by the violent boiling, or even water splashed over by the motion of the vehicle, has undergone many changes. Often an erection called a *steam-dome* serves to cover the top of the steam-pipe which, within the boiler, turns up and receives the steam by an expanded mouth like a chimney raised to nearly the top of this dome. In the present engine a tube s s extends along the whole back of the boiler, and collects the steam by a line of long slits on its upper side. The centre of its length communicates with the box C, from which descend the pipes *e e* to the valve-boxes of the cylinders *h h*, and the eduction pipes from these same boxes go forward, as seen in the elevation at *g*, and turn into the *smoke-box*. This is a cylindrical addition to or continuation of the front end of the boiler. Into it the numerous tubes *t t* pour the products of the fire, and from it the chimney ascends. The cylinders are, in many engines, placed in a downward enlargement of this box, the better to confine their heat; and in all cases their used steam is brought here and made to issue upwards from a tube tapering to a mouth like a jet directed up the chimney. This is called the *blast*, and has an important effect in increasing the draught through the fire.

The cylinders, however placed, always act in the simplest and most direct manner on the driving axle, by the piston rod *i*, which slides between guides, and the crank rod *k*, working the crank *l*, in this case outside, but often inside the wheel. Outside of this again, is the excentric *n*, whose rod works directly, but by a peculiar connexion, as will be seen, the rod *s* of the slide valve in *f*. The feed pump, each side having one, is in this case placed at *x* in a line with the axis of the cylinder, and the piston-rod being prolonged through *both* ends of the cylinder (evidently an advantage wherever it lies horizontally), its front end forms the plunger of the pump. This draws its supply up through a ball-valve from the pipe *x' x'*, whose hinder end is coupled by an ingenious yielding joint to a pipe descending from the tender. What the plunger has thus drawn, it impels up through another ball-valve into the pipe *x''*, by which it enters the boiler. Thus the whole of the *propelling* machinery, or that worked by the steam, is as simple as any steam apparatus can well be conceived.

The remaining functions, necessary to the *management*, or which must be performed by the hands of the driver, through proper mechanical aids, are seven. 1st, regulating the *pressure* of steam; 2d, regulating the *supply* of steam to the cylinders (which includes of course starting and stopping); 3d, regulating the *generation* of steam, *i. e.* the rate of combustion in the fire; 4th, regulating the supply of water; 5th, reversing the order in which the slide-valves produce the strokes, and thereby the direction in which the wheels revolve; 6th, letting water out of the cylinders; 7th, sounding an alarm.

The object, then, being to bring the handles for all these seven operations within reach of the driver standing behind, there are almost countless varieties of disposition for these details, but in the present instance we have (1) the safety-valves both situated on the cupola *a*, one locked up, the other governed by a lever, of which the end is held down by the spring balance *b*, similar to those used for weighing with a straight scale, (not a dial.) It is evident that by turning the nut that holds down the valve-lever, the screw seen above will be lifted through it, and the spiral spring stretched upward, and kept extended by a strain, which, as soon as the upward tendency of the valve *exceeds*, it will open by extending the spring still higher; and the amount of this strain is seen by the scale. 2. For regulating the supply of steam, the horizontal wheel turned by handles *d d*, pushes forward or withdraws the long rod passing into the box C, where its end moves (as seen in Fig. 2065) a pair of shutters sliding over the apertures of the steam-pipes *e e*, these shutters being pressed apart by a cushion of steam. 3. The intensity of the fire is regulated by altering the aperture of the blast of used steam in the chimney, which is the chief source of the draught throughout. To this end the blast pipe, which is formed by the meeting of *g* with that from the opposite side, terminates just above *j j* in the form of a hollow wedge, of which the two inclined sides turn on axes at their feet. which axes, coming out of the smoke-box, appear at *j j*, but these two plates are pressed together like lips at top, by springs. Close to the driver's right hand, but hidden here by the upper part and guard of the driving-wheel, is a winch, which, by turning a large screw, advances



STEAM. CRAMPTON'S RAILWAY LOCOMOTIVE ENGINE.

or withdraws through a short space the long rod $j'j'$, which, it will be seen, moves a short arm descending from the first j, and another arm therefrom similarly affects the second j, so that the two plates turning on $j\,j$ as centres are simultaneously approximated or separated from each other at top, regulating the aperture as required. 4. For the regulation of the supply of water, first the size of the feed-pumps is made such as to supply, when left alone, more than can ever be required under any circumstances. Next, a cock of variable aperture is placed where the feed-pipe x'' enters the boiler, and governed (that of each side separately) by a simple gear not here visible; and then a small *return-pipe* is carried from near this cock down to the pipe x', by which all the feed-water would return and never enter the boiler, were not the entry to the return-pipe made to be more or less closed by the same cock that enlarges or reduces the aperture into the boiler. Without this pipe it is evident that the mere reduction of the entry to the boiler could not reduce the quantity injected per stroke, but only impede the engine by its resistance, until the pipe x'' burst, which it *must* do if without escape for the compressed water. 5. The gear for *reversing* the course of the engine is by far the most elaborate, and that in which most variations have been used. The principle is to have always *two* excentrics for working each valve-box, one to be used in travelling forwards, the other in backing, and of course fixed on the axle with their greatest projections in opposite directions, as seen at n and o, best in the separate figure which represents the reversing gear alone. It is evident that when the rod of one, p, is withdrawn, that of the other, q, must be thrust forward, and *vice versâ*, so that they would contrarily work the slide; one making it to *precede* the piston by half a stroke, and the other to *follow* it by the same interval. The problem is how to transfer the slide-rod s from the influence of one of these to that of the other, without a shock. It is here effected (as in the most modern engine), by a kind of link r connecting the ends of the two excentric rods $p\,q$, and in which link the head of the slide-rod s may slide to or fro. This rod s, however, keeps always in the same straight line, and it is the ends of r or of the excentric rods $p\,q$, that must be successively brought *to it*, and not it *to them*, to place it under the governance of a fresh excentric. For this a chain of levers is used, beginning at the lever v, which has a handle at the top, and its fulcrum at a horizontal arbor or axle u. Pulled back into the dotted position, its lower end, below u, thrusts forward a nearly horizontal bar, seen jointed at its end to a short arm from the second arbor or axle t, which is thus moved similarly with u, about a quarter round. This arbor, extending all across the carriage, bears near each end such a lever as that to which the weight w is attached. The action of pulling back v, it will be seen, lifts w, and depressing the other end of its lever, draws down by a connecting bar the top of the piece r, together with the whole triangular assemblage formed by $p\,q$ and r, which must move together, preserving their *relative* positions. It brings down p into nearly the *absolute* position commonly occupied by q, thus making p instead of q the governor of s, and reversing the motion of the slide, and hence of the whole engine. But in this movement the head of s is successively in every part of the length of r, so that the change is gradual; and could we stop exactly when the head of s is at the middle of r, the slide would not be worked at all, the middle of r keeping always at the same distance from the axle, because one of its ends is always as much thrust forward as the other is drawn back, by the exactly contrary motions of p and q.

The next want, that of draining the cylinders from time to time of any water that might accumulate in and endanger them, is accomplished by small cocks $y\,y$ at each end of them, all four connected and opened at once by pulling up the rod y'; and for the last, a noisy signal or alarm, the steam-whistle z, consisting of two hemispheres or bells, mouth to mouth, and a flat disc between and nearly touching both, has been found effective.

STEAM-NAVIGATION. There is evidence that the propulsion of vessels afloat was the first useful purpose for which any one attempted to store up the power of steam; and the first (except that of military projectiles) to which fuel-power, or the motive effect of combustion, was ever applied. In 1543, before moderns had thought of settling by experiment their notions of the simplest laws of matter and motion, and consequently before their physical knowledge had made any advance beyond that of Ptolemy and Hero, (some seventeen centuries arrested by false learning,) it is recorded that one Blasco de Garay effected, at Barcelona, the propulsion of a boat, without sails or oars, by an apparatus, of which a *large kettle of boiling water* was the chief feature. As the "Pneumatics" of Hero preserved the memory of various toys and automata moved by the reaction of issuing jets of steam, it seems likely that the effect of such a jet or jets directed backward from a boat into the water would be tried; and such, we fancy, must have been the nature of Garay's steamer, involving as it does no moving machinery, nor so much as Worcester's or even Galileo's acquaintance with the properties of elastic fluids.

Worcester does not mention this among the possible uses [1] of his grand discovery; but every succeeding

(1) Some have imagined that he did so in one of his inventions called the "quintessence of motion," by which he boasts that he could "make a vessel of as great burden as the river can bear, to go against the stream, which, the more rapid it is, the faster it shall advance." This dependence on the speed of the current, however, clearly shows that the current, and not any artificial motion, was his prime mover. Of course his propelling apparatus must have acted not against the water, but against the *ground;* and, with this proviso, it would be as possible for the current to move bodies against itself, as we daily see it is for the wind to urge sailing vessels against itself. The comparatively motionless fulcrum which, in sailing, is furnished by the water, would in the other case be afforded by the bottom or banks; nor can we see any reason why the power of rivers should not thus be used to transport goods *up* as well as down the stream, now and at any future time, with as much saving of human labour as this far-sighted philosopher anticipated.

advocate and improver thereof, from Savary and Papin downwards, makes special allusion to it; proposing generally to effect it by the present commonest form of propeller—the paddle-wheel. Thus steam-navigation has been, among the scientific, quite as old a project as the steam-engine, if not older, only waiting the attention and enterprise of wealthy men for its realization.

Before Watt's invention of the double-acting engine, the difficulty of getting a *continued* motion, *i. e.* a *rotation* from steam, led to various expedients for using the intermittent motion of the atmospheric piston, by applying it to propellers more easily moved by it than the wheel, which was yet allowed to be abstractedly the best. Dr. John Allen, in 1730, was the first proposer of the *pump* or *bellows* mode of propelling, *i. e.* by forcing out a stream of water or air in the contrary direction to that in which the vessel is to advance; a method which has since been the subject of numerous patented failures.[1] But Jonathan Hulls, in 1736, not only most logically and satisfactorily demonstrated the practicability of steam-navigation, but planned a steam-boat, itself quite feasible, and as near our present ones as any driven by atmospheric engines could perhaps approach. Two such engine-cylinders are placed abreast, as at present, and their pistons suspended by cords or chains passing over pulleys to the stern, beyond which a frame projects, and carries one large paddle-wheel, like an undershot waterwheel. Near the two ends of its axle are two small wheels, round which the said chains make one turn, and then hang down and end in weights sufficient to draw up the pistons. These two wheels are loose on the axle, and connected with the paddle-wheel by a ratchet-wheel, so as to oblige it to turn with them in one direction, but not in the other, (as the ratchet-wheel enables a clock or watch to be wound up without turning its hands, though the same axle cannot turn the contrary way without driving them.) The pistons being pressed down alternately, would each drag round the axle and wheel through a certain space, and then leave it to be drawn round an equal quantity by the other piston, while the first was pulled up to the top of its cylinder by its counterweight; thus imparting between them a continued rotation to the paddle-wheel; which might even have been made quite uniform by having three pistons instead of two, and making the connexion by cranks 120° apart, as in Watt's second proposal for rotation. But this mode of "carrying ships out of or into any harbour, port, or river, against wind and tide or in a calm," although patented for 14 years, was far too advanced beyond the general knowledge of the time to be then introduced.

(1) This stream has always, we believe, been tried *single*, and from the *stern*, although the natural exemplars of it, the gills of fishes, (certainly auxiliary to, if not principally concerned in, their propulsion,) are on each side, and, like our paddle-wheels, ahead of the centre of gravity, and a little ahead of the widest beam of the animal. Has this mode of propelling, after all, had its fair trial? If capable of competing with others at all, it evidently has some great advantages over all of them—in the freedom and independence of the evolutions which it would render easy, even without the rudder.

The celebrated mathematician, Daniel Bernouilli, afterwards turned his attention to the subject, and seems to have leaned to a kind of artificial *fins*, constantly under water, which have never been fairly tried.

In 1757 this problem was made the subject of the prize offered by the French Academy, which was awarded to the said Bernouilli for his demonstration of the use and effect of paddle-wheels, and other propellers to be moved by the expansive force either of gunpowder or of steam. No practical trials, however, followed. A Swiss clergyman named Genevois failed in some attempts with imitations of a *duck's-foot;* and the matter then remained in abeyance for about 20 years. After this a variety of serious attempts, at considerable pains and expense, were begun; three successively in France by the Comte d'Auxiron, M. Perrier, and the Marquis de Jouffray, all of whom succeeded in producing a slow propulsion, and the last built a steam-boat on the Saone no less than 147 feet long: his experiments were, however, interrupted by the Revolution. The attempts of M. Seratti in Italy, and of James Ramsay, John Fitch, and Oliver Evans, on different rivers of America, were less successful. Watt's rapid improvements of the engine, however, then completed, ensured to Britain the glory of constructing the first profitable steam-vessel, which was done by William Symington, a Scotch engineer, at the instigation and expense of Patrick Miller,[2] a gentleman of Dalswinton, near the Forth and Clyde Canal, on which this boat ran, at first, in 1788, at the rate of 5 miles an hour, and afterwards, with larger paddle-wheels, attained 7 miles an hour. Another, called the "Charlotte Dundas," was constructed in 1801, and continued in use on the same canal many years, as a tug, capable of towing at once two vessels of 70 tons each.

Meanwhile, the attempts of the three Americans above-named all failed to attain a profitable speed; as did that of Earl Stanhope with a revival of the artificial duck's-feet; and that of Fulton, another American, then residing at Paris, where his first boat broke under the weight of its machinery, and a second, built in 1803, could not attain a useful speed. This Fulton, however, going the same year into Scotland, saw the "Charlotte Dundas," was taken a trip in her by Symington, and received from him a full explanation of her machinery, which he minutely examined, noted, and questioned Symington upon. "I considered," says that engineer, "the more publicity that was given to any discovery intended for general good, so much the better; and having the privilege secured by letters patent, I was not afraid of his making any encroachment upon my right in the British dominions, though in the

(2) The war between France and England led to various projects at that time for propelling rafts or transports, with head to wind, or in a calm; and this Mr. Miller, after proposing to do so by paddle-wheels driven at first by the crew working at capstans, and afterwards by windmills, was led at length to think of steam power; but had no share in the contrivances for applying it, which seem jointly due to Symington and Henry Bell (afterwards referred to) who assisted him without sharing either the honour or the profit.

United States I was well aware I had no power of control."

Having ordered an engine of Boulton and Watt, (it is said under an assumed name,) Fulton proceeded to America, and with a capitalist, named Livingstone, obtained there a patent for what he called his *invention* (not introduction) of steam-boats. They then, by the aid of drawings and advice gratuitously tendered them by Mr. Henry Bell, an Engish engineer who had also assisted Symington, built a vessel to receive the engine ordered of Boulton and Watt; and in 1807, *eighteen years after* Symington's triumphant steaming of *seven* miles an hour at Dalswinton, this American celebrity made its first trip on the Hudson river, attaining barely *five* miles an hour. The State of New York had offered, as a prize, the monopoly of steam-navigation in its territory, to the first who should propel a vessel in this way four miles an hour, and a native engineer, R. L. Stevens, had contrived one which, only a few days after Fulton's, achieved equal success. A greater honour, however, than the expected prize, fell in consequence of this to Stevens's vessel; for being thus debarred the use of it in that State, he had the boldness to proceed to Delaware by sea, thus making both the first marine and the first ocean steam-voyage, many years before any one else ventured to steam out of rivers, and 32 years before ocean steamers were thought practicable.

Peace, and the travelling propensities of a nation of refugees settling far apart along boundless rivers, caused the commercial value of steam navigation to be immediately realised in America, so that two more boats were commenced by Livingstone and Fulton even before the death of the latter in the following year; and Stevens soon made such improvements as raised the speed attainable to 13 miles an hour; developing the mode of connexion between the pistons and cranks still most used in America; and even one improvement, that has not yet been adopted in Europe, the division of each paddle-board into 3 or more portions arranged like steps, to obviate the shock of a whole board entering the water at once. Meanwhile in Europe, even in Scotland, the invention lay neglected, and it was, as it were, reintroduced and almost regarded as an American one. Nor was it, until the year 1812, that the first passage-boat was made to ply on the Clyde, and so little was the power of engine necessary to propel a large vessel then understood, that it was only of 3 horse-power. It became soon evident that, to attain any useful speed, the engines and boilers must occupy a very considerable portion of the vessel; and, to save room, all condensing apparatus was omitted, and the high-pressure steam allowed to escape at each stroke, as in locomotives, and in many steamers in use to this day in America, where the economy of fuel is a minor consideration to that of space and machinery. As improvements were made in compactness, however, the condensing apparatus became universal in English steamers. The first sea-going boat was established in 1815, between Glasgow and London; and in 1817 the number of such boats had increased sufficiently to call for legislation against accidents, which had already been more numerous and destructive in England than in the whole time in which steamers had been multiplying in America. The regulations then made were to the effect of forbidding all use of cast-iron in boilers, (which had hitherto been made often wholly of that material, to avoid the difficulty and expense of rivetting numerous seams,) requiring them to be tested when first made, with a pressure of water; and to have 2 safety-valves, one open to the engine-driver and all persons on board, the other visible, but inaccessible, and loaded with no more than 1-third of the pressure with which the boiler was tested, or 1-sixth of what it is calculated, from the data of the strength of the materials, to burst with. These laws are still incomplete in fixing no minimum time for the continuance of the testing pressure (which may not effect what a far lower pressure might do in a longer time); in requiring no periodical trial of the locked-up safety-valve, and especially no periodical re-testing of the boiler as it progressively wears and corrodes, and becomes weaker from day to day; and in fixing no minimum size of safety-valve relatively to that of the boiler. Neither will leaden or fusible safety-rivets be common unless enforced by law, nor effectual unless obliged to exceed a fixed size; nor will boilers be tested with *air* (a far different trial and closer imitation of what they are to bear habitually than the pressure of *water*, only tending to expand into a thousandth or 10-thousandth more space); nor will engine-drivers be fined for the steam showing, by opening the locked-up valve, that they have overloaded or neglected the accessible one.

The good effects of such enactments, however imperfect, have yet been shown in the proportion of English to American accidents becoming ever since that regulation exactly reversed, so that there are now ten passengers killed in America to one in England.

After Henry Bell, the joint originator with Symington, and the reviver in 1812-13 of British steam-navigation, Mr. David Napier contributed most to its improvement. He introduced the mode of connexion most common in Europe, called the *side-lever* connexion, and was the first to succeed in forming condensers without injection, the object of which was to enable sea-going steamers to use fresh water, the same fluid circulating through the boiler, engines, condenser, and feed-pump, without admixture or loss. By this means, the hard incrustations deposited by salt-water in the boilers would be obviated; but the plan does not seem to have been yet made perfect enough to be extensively used, for Watt's mode of condensation is still almost universal.

The triumph of steam-navigation may be said to be completed by the establishment of regular trans-oceanic packets. Although the *Savannah*, a 300 ton American steamer, came to Liverpool in 1819 and returned, and although the *Curaçoa* in 1829 made two voyages between Holland and the West Indies, both depended chiefly on their sails. It was just a century after Jonathan Hull's neglected proposition, and half

a century after Symington's first realization of it, that the first keel was laid expressly for an Atlantic steam-ship, the *Great Western* of Bristol, which in April, 1838, crossed to New York, and in May returned; preceded at an interval of three days by the *Sirius*, of Liverpool, a vessel not built for but adapted to this new service; each having performed without supplies above 3,000 miles, at an average rate of 210 miles a day. The *Great Western* consumed 655 tons of coal on her way out, which was 3125 miles in 17 days; and 392 tons on her way back, which was 3192 miles in 15 days. There is a great

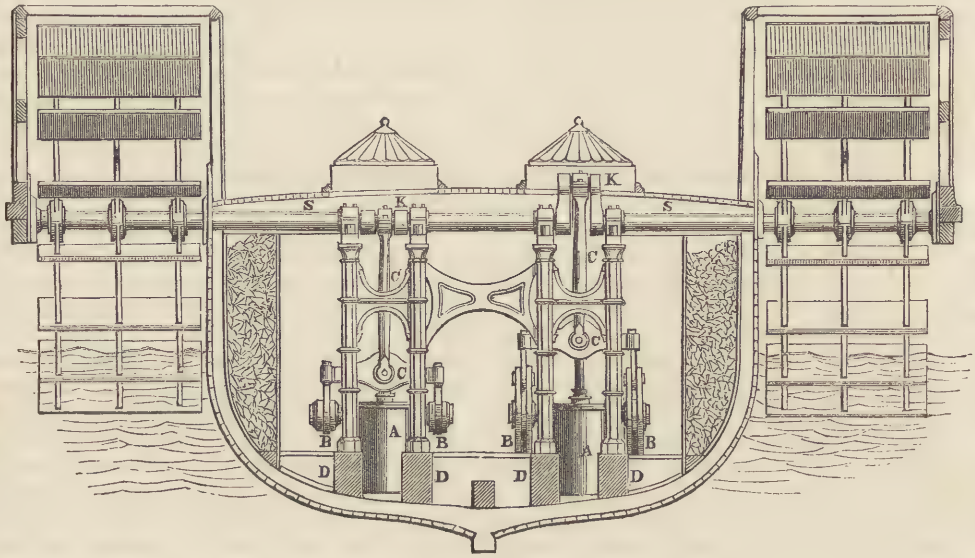


Fig. 2066. CROSS SECTION THROUGH A "SIDE-LEVER" STEAMER.

preponderance of westerly winds, it will be remembered, throughout the temperate zone of the Atlantic.

Until within these ten years, only one general form of propelling apparatus had been used for all steamers,

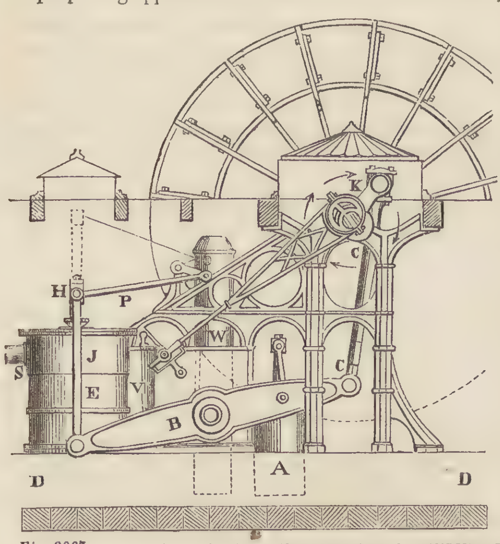


Fig. 2067. LONGITUDINAL SECTION, SHOWING ONE CYLINDER AND CRANK OF THE "SIDE-LEVER" ENGINES.

and is still by far the commonest. It consists of two paddle-wheels, fixed on the outward projections of one great shaft or axle, crossing the vessel at or a little below the level of the spar deck, and at from two-fifths to not quite half the extreme length of the vessel from the head. To diminish the extreme width, the vessel is often contracted, like a wasp's body, at the part crossed by the shaft. The whole axle rests and turns on 8 bearings, those for its ends being in the overhanging frames that carry the paddle-boxes, the next two in the sides of the vessel, and between these are four other bearings, on iron frames rising from the bottom of the vessel, where they stand on four very stout beams laid longitudinally, marked D D D D in Figs. 2066 and 2067, which serve to distribute the weight of the machinery over a great number of the ribs of the vessel; the difficulty of a sufficient foundation, which was greatly insisted on by those who ridiculed steam-navigation, throughout the half century of its invention, being really far less formidable in a boat on the equable support of water, than in any circumstances on land. Between the first and second of these frames, reckoning either way from the centre, the axle is interrupted to form a crank, so that these divide it into three pieces, called respectively the two *paddle-shafts* and the *intermediate shaft;* and the two cranks are in planes at right angles to each other, as in a locomotive, in order that the action thereon of the two pistons, however communicated, may keep up an equable rotation, by each being in the middle of its stroke when the other is changing its motion. So far all paddle steamers are alike, and we may add that (although we have seen a small American steamer with the cylinders laid horizontally) the cylinders are so much better vertical than in any other position, that their verticality may also be regarded as an uni-

versal character; and they stand of course in the planes of revolution of the two cranks, or equidistant on each side of the middle plane of the vessel; though sometimes before, sometimes abaft, and sometimes directly under the cranks, according to the means used for imparting their motion thereto, which forms the sole element of variety in paddle-driving engines.

To place the cylinders *under* the cranks, and carry a connecting-rod from the head of each piston-rod to the crank, (in fact, the propelling parts of a locomotive, only placed upright instead of horizontal,) has only answered for very slow vessels; because, as there must be height above the cylinder for, *first*, a piston-rod of its own length, *then* a connecting or crank-rod at least as long, (and the longer the better for uniformity of motion,) the length of stroke can evidently be never more than one-third the height from the ship's bottom lining to the top of the circle described by the crank; or, we may say, one-third of her inside depth, because, although the crank rises its own radius, or half the length of the stroke, higher than the axle or deck, the depth of the foundation beams D, and of the stuffing-box, cylinder-ends, and junction of the piston and crank-rods, will always more than measure this half-stroke. Now, two engines of the usual proportions, and no longer a stroke than a third of the vessel's inside depth, are quite inadequate to give it, with the usual pressures of steam, the velocity now required by the public in steamers.

Some more circuitous connexion, then, is almost universal. The above is called a "*direct-action*" engine, and properly should be the only one so called; but the name is extended to all that have no lever of the first kind (see STATICS) interposed between the piston and the crank, *i.e.* all in which they both rise or fall at the same time. Thus all engines become divided, as regards this, into *direct-action* and *beam* engines; of which we will first notice the latter, because they were the first used, and are still the commonest in large and important vessels.

These are again subdivided into those whose beam or lever is *above* the crank, as in land-engines, [see STEAM-ENGINE, Figs. 2039 and 2053,] and those in which it is *below*, as about to be shown. The former are exclusively confined, or nearly so, to America, and are commonly called *beam*-engines. The others, having to each cylinder two beams or levers placed as low as may be possible, one on each *side* of it, are hence called *side-lever* engines, and are still the commonest in Europe, at least for large vessels. In these a *cross-head* is necessarily placed on each piston-rod, projecting each way beyond the sides of the cylinder, and from its ends hang the two rods that work these beams, while the further ends of the beams are united by a *cross-tail* from which ascends the rod that works the crank. At first sight, this, although having more parts, would seem to be greatly superior to the American arrangement, which exposes its beams with all their joints and appendages aloft to the weather. But it must be remembered, that the proportion of the stroke to the depth of the vessel is here still limited, as there must be depth for at least the whole length of the crank-rod below the crank when in its lowest position; whereas the American plan exacts only depth for the crank itself to revolve, and is thus suited to the very shallowest vessels, or those approaching the nature of rafts. Although a most inartificial expedient, therefore, something like leaving part of an animal's machinery outside his skin, it cuts the knot or evades the difficulties of contriving a good steamer; and must obviously continue to possess the shoaly and uncertain rivers of a new and unimproved country.

The common European or side-lever machinery is shown in Figs. 2066 and 2067; the former a longitudinal section through the keel, the latter across the space left on that side of the axle farthest from the cylinders or *engines*, (as they are commonly called,) which may be either before or abaft it. When before it, they oblige the steam-pipe to be conducted from the boilers (which are always aft) through the whole space occupied by the machinery, but we have shown it simply entering one engine at E. The steam passes round on each side the cylinder by the encircling hollow belt J, partly serving the purpose of the jacket, to arrive at the valve-box V. The sliding kind of valve is universal, and always moved by an excentric-rod from the axle as here shown, separate excentrics of a different shape called *cams* being provided for regulating the grade of expansive working. [See STEAM-ENGINE.] The used steam descends into a condenser below W, in a water-tank; and the air-pumps, one for each engine, are at A A, each connected with the two beams B, in just the same way that the working piston itself is, by a cross-head, from the ends of which descend rods to that point of each beam which describes the properly diminished stroke. The cross-head H of each engine (and sometimes that of each air-pump too) is kept in one vertical plane by the peculiar kind of parallel motion seen at P, composed of a long and a short arm, the short one attached to a fixed point. This, of course, is repeated for each end of each cross-head. The air-pump expels the hot water into the well W, whence the feed-pump (too small to be represented in the figure) draws its supply.

It is evident that in these side-lever steamers, the length of stroke relatively to the vessel's depth, (and consequently the proportion of power to size, and hence the speed,) is limited only by the necessity of depth below the crank for its rod C C, which must be at least as long as $1\frac{1}{2}$ times the stroke (or diameter of crank circle), to give a tolerably uniform motion. There are many contrivances for placing the cylinders under the shaft, and yet avoiding much more (or even any more) limitation than this; and all such are usually called *direct-action* engines, of which we will now notice the chief.

I. The piston-rod may ascend, when highest, even into the hollow of the crank, *i.e.* above the level of the axle, if we place on its head some horizontal cross piece as on a T, lying fore and aft, and projecting further each way than the circle described by the crank, and then raise from its ends two rafter-like

pieces extending to any required height, and from the top where they meet, suspend a rod to the crank, which will thus be worked from above, though the cylinder is below it. This arrangement is called the *steeple*-engine, from its high and pointed form. It gives an awkward, top-heavy impression, from the great apparent mass lifted bodily above deck at each stroke; which may account for its infrequent use, although it really saves, or may save, more depth than any except Messrs. Maudslay and Field's *double-piston-rod* arrangement. It requires the verticality of motion in so large a mass to be insured by guides, against which friction-wheels should roll.

II. The *double-piston-rod* engine, above alluded to, although one of the latest inventions of its eminent authors, is simply a refinement on the above. As there are two piston-rods to each piston, the centre of the cylinder-cover is plain, and this allows the crank when lowest to barely clear the said cover, thus saving, as compared with the "steeple," the depth of a stuffing-box, and also of the T head, forming the base of the triangle or steeple, which piece requires some depth, as it resembles a scale-beam, supported in the middle only, and loaded at each end only. Messrs. Maudslay and Field's two piston-rods are near the sides of the cylinder, but neither on its fore and aft diameter, nor on that crossing it, although nearest to the latter, as near as they can be to clear the axle which passes between them. The oblique position is evidently necessary, in order that they may interfere neither with this, nor with the revolutions of the crank. The whole is the shallowest arrangement possible without a beam above deck, and has accordingly been adopted on such shoaly rivers as the Rhone, the Indus, and the Sutledj.

III. The *oscillating* engine was the capital invention of Mr. Goldsworthy Gurney, but decried and

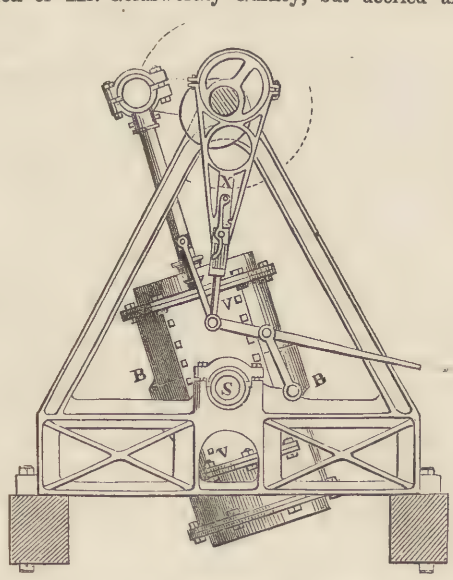


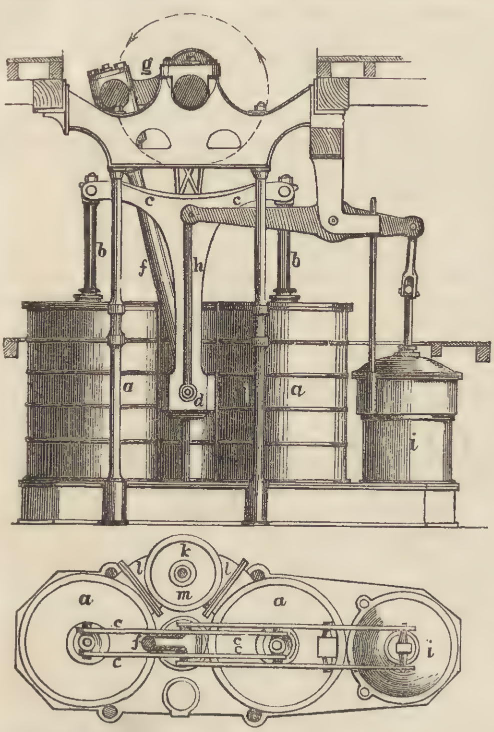
Fig. 2068. OSCILLATING CYLINDER.

neglected until it was introduced into boats by Maudslay about 20 years ago. As seen, in Fig. 2068, the piston-rod is made to serve also as connecting-rod, its top embracing the crank-pin. As this must, in such case, describe a circle, the rod moving it must be allowed an angular vibration to and fro, as we see in all crank-rods. To permit this in the piston-rod, the whole piston and cylinder must be allowed to partake in the oscillation, which is done by supporting the cylinder solely on 2 *trunnions*, like those of a cannon or a transit telescope, one of which is seen at S. Of course the steam can only enter and leave it through one or both of these trunnions; therefore it must be directed thence to the ends of the cylinder by passages and valves all moving bodily therewith, independently of the proper motions of the valves. This is accomplished commonly as here shown, by the valve-box V V being screwed to the side of the cylinder, and its rod moved by an arrangement conducting motion from an excentric on the fixed axle. All this, however, is needless, as properly placed openings in the hollow trunnion S, and the cylindrical surface in which it turns, would answer all the purposes of valves, valve-boxes, valve-rods, valve-gear, and excentric, and by thus admitting the steam through one trunnion, and exhausting it through the other, we should have probably the very simplest steam-engine (as regards the number of parts and the amount of workmanship) possible. Its moving parts need scarcely contain 10 pieces exclusive of screws, nuts, &c., the passages being cast in one with the cylinder, as the steam-belt B B and the trunnions always are. The depth required below the axle here is evidently once and a half the stroke. It is not therefore so compact as the "steeple" forms, but it has the advantage of requiring less framing, and distributing its weight better than probably any other form of engine.

There seems still much timidity in extending the use of this excellent form beyond the smallest class of marine engines. Mr. Bourne, in his "Catechism of the Steam-engine," gives it the preference over all other engines, not only for sea, but for all land purposes, including locomotives; and if well proportioned and simplified, it would seem not unlikely to supersede them all, except in works of great magnitude, perhaps even in those. In the application of this engine to boats, one air-pump, large enough for both engines, is placed between them, and worked by a third crank in the middle of the axle.

IV. A *double-cylinder* arrangement, (that is, having 2 cylinders to each crank,) Fig. 2069, has been employed by Messrs. Maudslay and Field in their largest steamers, whose power is perhaps such as, to obtain from 2 cylinders only, would need a magnitude hardly yet attainable. The valve-box *k* is common to two cylinders, as seen in Fig 2070, a plan of the pair on one side of the vessel; and its slide is worked directly from an excentric on the axle just over it. A small passage is always open at *m* from one cylinder to the other, both at their top and bottom, to insure equal pressure in both. The piston-rods *b b* bear two T or Y-shaped pieces *c c*, between which the crank-rod *f* ascends from their foot *d* to the crank. In the example whence the figure is taken, the con-

nexion occupies much more height than is necessary. It will be seen that the limitation of stroke relatively to the depth of the vessel is nearly as in the "steeple" engine, the pieces *c c* however admitting such a formation as to allow the crank to descend when lowest to a level with the tops of the stuffing-boxes. Rods



Figs. 2069, 2070. SIDE ELEVATION AND PLAN OF ONE PAIR OF MAUDSLAY'S DOUBLE-CYLINDER ENGINES.

ascending from the 2 sides of *d* work the 2 levers, from whose united ends the rod of the air-pump *i* depends, and from other points the feed and bilge pumps.

V. A still more compact invention of the same artists, the *annular cylinder* engine, seems to pre-

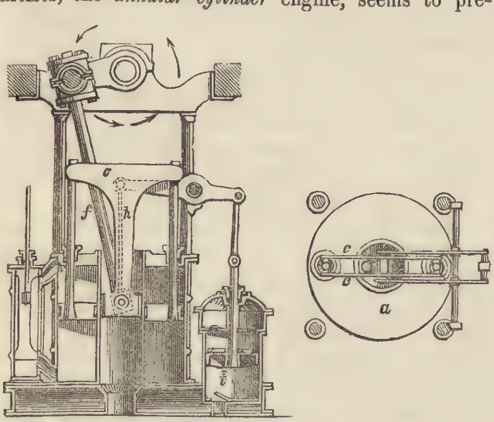


Fig. 2071. SECTION AND PLAN OF MAUDSLAY'S ANNULAR MARINE ENGINE.

sent the largest power possible in a vessel of given draught, without machinery above deck, and that in the least possible space. Each cylinder, Fig. 2071, consists of 2 concentric ones, and the piston fills only the space between them, which, however, is at least $\frac{3}{4}$ths of the whole area. From this *annular* piston two rods support the T or Y pieces precisely as in the last described variety, which this resembles in all the remainder of its disposition, except that the valve-box is attached to the after side of the cylinder. The progress from that form indeed to this, is obvious and unavoidable. The passages at *m*, Fig. 2070, formed the two cylinders virtually into one chamber, nearly surrounding the space in which the crank-rod descended, which space now becomes the inner cylinder; and as the annular piston here has a less extent of outline than two circular pistons equalling it in area, a saving of friction arises from the change, as well as a more important one of stowage-room.

Much trouble has been wasted in attempts to carry the paddle-boards through the water more perpendicularly, or quite perpendicular to the course of the vessel, for which purpose they have even been mounted on endless chains passing round *two* drums, like the present paddle-wheels, on each side. But with the single wheel it is easy, by making each board turn on two pivots in its ends, to keep them all, by a little appendage on the parallel-ruler principle, vertical throughout their revolution, which at first sight *seems*, besides the above advantage, to make them enter and leave the water edgewise and without splash, and the considerable loss of power absorbed therein. This, although it once led to the extensive trial of such *feathering* paddles, is entirely erroneous, arising from the wheel being regarded as if its centre were at rest, or as if, the vessel being at anchor, the object was only to excite a current in the water. But when we combine the forward motion of the vessel with the rotation of the wheel, we find that the boards, if fixed to it radially, will each take successively somewhat the positions shown in Fig. 2072 at *p p p p*. There is a certain circle R R, smaller than the wheel's periphery, so moving that its speed of rotation just equals the vessel's rate of advance, so that in this circle (as in the tire of a carriage wheel) the lowest point is stationary, and the highest advances twice as fast as the axle. Consequently, any point in this circle, or at this particular distance from the axle, describes the same series of curves *c c c c* (called *cycloids*) that a point in the edge of a rolling wheel does, and hence this is called the *rolling circle*. It evidently cannot be a fixed circle in any wheel, but varies in size according to the performance of the vessel, or the proportion of the effect obtained to the power spent. A wheel may be turned so slowly as not to propel the vessel at all, and then the rolling circle will have no diameter. When largest, it evidently can never equal the diameter of that passing through the centres of pressure of the boards, for then the whole power would be spent in propelling the vessel, and none in driving back water, which is impossible. The parts further from the axle than R R must not only cease advancing when at the bottom of their course, but *return* or *retrograde*, and

describe a loop, as seen in the dotted curve *p p p p*, described by the outer edge of a board; and it will be seen that the board, during its immersion, moves very like the blade of an oar most skilfully *feathered*, and enters and leaves the water almost edgewise, at least far more so than it would do if kept always vertical.

But the positions the boards should keep, if we would have them feather quite accurately, would be as

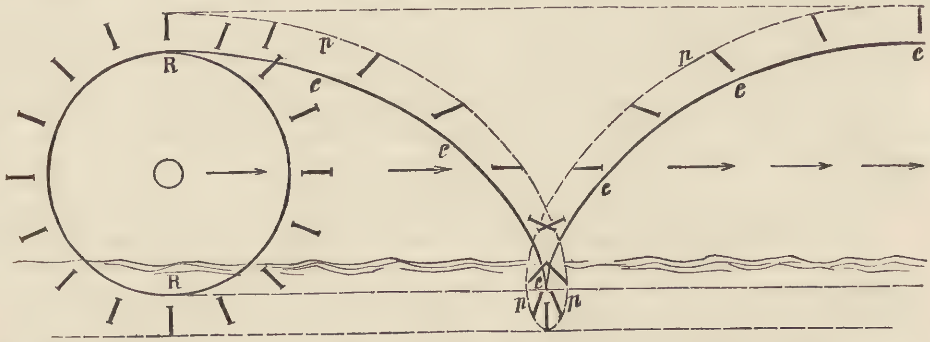


Fig. 2072.

in Fig. 2073, all diverging from a point C at the top of a circle, whose size depends on that of the rolling circle. The better the performance of the vessel, the lower will this point C become.

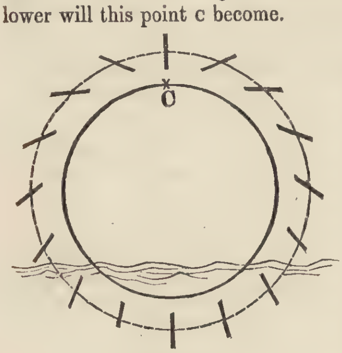


Fig. 2073.

To produce something like this movement of the boards, (though necessarily always alike in the same wheel,) is the object of the modern feathering wheels, which are all similar in principle, and will be understood from Fig. 2074. The principle was first introduced in Morgan's wheel, from which the others only differ in details of the connexions.

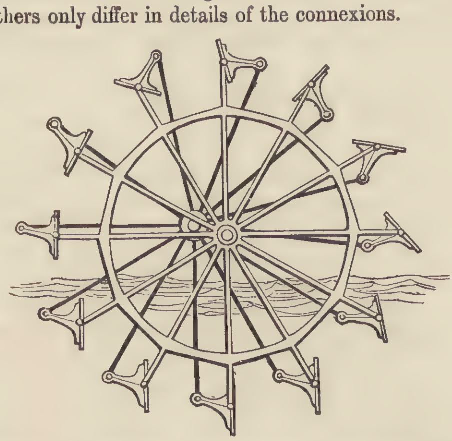


Fig 2074. PRINCIPLE OF MORGAN'S AND OTHER FEATHERING PADDLES.

The white arms are those of the wheel, formed into one rigid frame by two concentric circles or polygons, of which, to avoid confusion, the outer one is here omitted The boards turn on axes at the corners of this outer polygon, and have each an arm projecting from the back at an angle of about 70°, and to the ends of these are jointed the black radii seen meeting at a centre a little in advance of, and higher than that of the wheel. This centre must be fixed to the paddle-box, and allow the several black arms to turn on it independently of each other, so that the angles between them may vary, and the modes of doing this, and still preserving the connexion and rigidity of the wheels, lead to the several varieties of feathering paddles; but it is extremely doubtful whether their saving of power compensates for the complication and presence of joints in a part so much exposed to violence, and especially for the weakness arising from the impossibility of giving the axle a bearing in the outside of the paddle-box. The difference of effect between rigid and feathering paddles is found to be very small when both are no more immersed than is now usual, although it increases very rapidly when the immersion approaches that represented in Fig. 2074.

The name *cycloidal* paddle has also been rather absurdly given to a variety of rigid paddle, in which each board is divided longitudinally into three or more strips placed as in Fig. 2075, in order that, as

Fig. 2075.

they enter the water, it may be less splashed than by one unbroken surface. The three enter it at once, but at different places, and they emerge from it successively, but at nearly the same spot. There is no

particular advantage in placing them with reference to a cycloidal curve, nor can the name be accounted for, unless as an advertisement.

From the earliest dawn of speculations on mechanical propulsion, the *screw* propeller, nearly in the forms now used, had been regarded among the most likely to succeed in water, and Bernouilli, in the middle of the last century, theorised upon this, as upon nearly every conceivable form of propeller, in the prize essay above-mentioned. Paddle-wheels, however, so took possession of the field of practice that nothing else was seriously tried, until, in the year 1836, Mr. J. P. Smith imagined a new and probably the best place for such a screw, viz. in a square aperture to be left open through the "deadwood," or thin solid prolongation always made from under the stern down to the keel, chiefly in order, apparently, to fill out a resisting plane back to the rudder, which, with open space before it, would not act. [See SHIP.] A company being formed to carry out this patented idea, Sir John and Mr. George Rennie alone, among English engineers, had the science to recommend and put it in practice.

The nature of this propeller is precisely that of a windmill or smoke-jack, only inverted in action, the machine acting against the fluid instead of the fluid driving the machine. At first, two extreme and opposite treatments of it were used, Captain Ericcson having patented one of almost as broad and shallow a proportion as the turning ventilators, and having 6 vanes at its circumference, three of which continued to the axis (the others being stopped by a ring about halfway between the centre and circumference); while Rennie adopted a single vane winding round the axis like the thread of a screw, performing one complete turn. At present a medium between these, viz. a screw of *two* threads, each making *half* a turn, has become general, but the varieties of curvature that have been tried are almost endless. The general enclosing contour has been made not cylindrical but conical, and that in both directions, but commonly with the larger end backward. The *pitch*, or rate of the thread's advance along the axle for each degree or other angular measure of its rotation, has been variously adjusted, and in Mr. Woodcroft's very successful screw, is made to increase gradually from one end to the other, so that a particle of water after undergoing the action of the part it first meets, may yet receive further impulse from another part. The whole of this increase only amounts to about a twentieth quicker pitch at one end than the other.

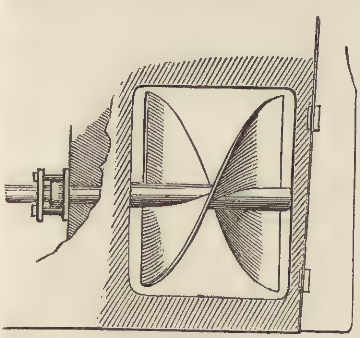


Fig. 2076.

Lastly, *flat surfaces* have been substituted for the threads by Captain Carpenter, who uses two propellers under the ship's quarters, and leaves the deadwood unperforated. A propeller with flat vanes resembles a sort of paper windmill, common as a toy in some places. It has the great advantage of enabling the vanes to be each so turned round as to come into one plane, offering no resistance to the sailing of the vessel when steam is not used. Mr. Maudslay has patented an apparatus for doing this with vanes not flat, but whose curvature is so managed, that, when thus turned, they are included in the thickness of the keel, and thus offer as little resistance as possible. Fig. 2077 shows the plan with the vanes in their working position; Fig. 2078 their plan when folded out of use; and Fig. 2079 their side elevation, *r r* being their full width, to which the aperture is adjusted, and *s s* the width they occupy when in action. A system of short levers moved by the rod B, fixes and holds them in either position, and when released by this, they are successively brought to the top of their circuit, and there turned into the required position by a tiller C. Previous to the contrivance of this *feathering* screw, the clumsy expedient of unshipping the whole mass was performed, or proposed to be performed, in sailing vessels, with auxiliary steam; and it has even been proposed by theorists to carry screws of different powers and qualities, and ship or unship them according to the hourly variations of weather!

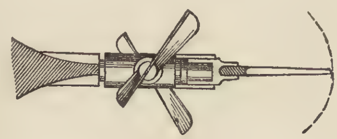


Fig. 2077.

Fig. 2078.

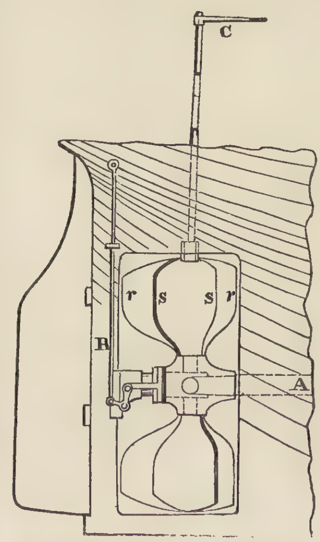


Fig. 2079. MAUDSLAY'S FEATHERING SCREW.

The difficulty that was found in the early trials of the screw, and perhaps still exists, only evaded a little, is the obtaining a sufficient velocity of rotation, with large engines and machinery of constant contact. The velocity best adapted to the paddles is such as to make the relation very happy between the circumference of paddle-wheels and the number of strokes

per minute easily attained by steam pistons of every size; or perhaps we should rather say, the number of strokes habitually used in land engines, and to which therefore their settled proportions and forms had been designed. It was forgotten that these proportions and forms were not laws of nature. The excessive subdivision, or rather *disconnexion of subjects* in the minds of a people accustomed to extreme division of labour, such as the Chinese or the English, leads at length to the regarding of purely artificial and arbitrary things, if a little out of our own peculiar province, as natural data. The length and breadth of a brick, or the proportion between the cylinder and steam-pipe of an engine, have been regarded by architects in each matter, much as we might regard the dimensions of the head and neck of a horse. It thus comes to be forgotten that the production of a good whole requires anything more than perfect producers of each detail, and perfect fitters to put them all together. There are Englishmen who really suppose that between good *detail-makers* and good *putters together*, a thing may be made; for the grand evil thus induced in every matter, and in most human affairs is, in three words, *want of architects*, want of Vitruvius-like regarders, (theorists,—to "theorize" is to regard or look at,) regarders of all the various subjects embraced in, or bearing upon, one work; for it is now the fashion carefully to portion out details and to collect together such only as are, or appear to be, related: each set of details has its own world of fancies and of connoisseurs, and it is rare to find two sets mentioned on the same sheet.

The reader will not be surprised, then, that as it is found that a canal horse can do most work when drawing at the rate of 220 feet per minute, it was concluded that all prime movers, and consequently all steam pistons should move at that rate; which law of nature has been so well known to those truly practical men, English engineers, as to have influenced all their practice for half a century, and prevented probably many more important things than screw steaming. This natural speed determined the natural proportion between the various parts of an engine of course, and hence the non-applicability of engines to turn a screw, which not being the work for which they were made, evidently could not be the natural propeller for steamers. The fact however is, that until we find a natural pressure for steam, there is no speed of piston more natural than another; and until we find a natural limit to the pressure at which steam can be used, there is no limit to the speed (and consequently the power) attainable in any given cylinder, except the velocity with which the air-pump valves fall into their places by gravity; and there is no conceivable reason why these should be moved by gravity, and not, like the other valves, by the engine gear.

Without such changes, however, the absurdity of employing four engines to turn one axle has been obviated by applying Bishopp's disc engine, (see Steam-Engine, and the steel engraving,) although the unequal wear is a great objection to this and all rotary engines. It seems better to use two common cylinders with such large ports and steam passages as to allow of the requisite numbers of strokes, and a diameter probably exceeding their length. Messrs. Maudslay and Field's method is to place these horizontally, and both on the same side of the axle. Wherever they act on different cranks, the arrangement must evidently be unsymmetrical or one-sided, and hence Messrs. Mather, Dixon & Grantham have a very neat way of turning one single crank by two rods descending from cylinders above it, each inclined 45°, so that they are at right angles to each other; and they increase the compactness by making these *oscillating* engines with their stuffing-boxes downwards, neither of which peculiarities is necessary. The turning of one crank by two pistons, each inclined 45°, was first practised in the great engine erected to drain the Thames Tunnel.

The screw shaft has also been driven by different kinds of flexible bands passing round it and a large revolving drum above, which is turned by the engines only once for every 3 or even 4 revolutions of the screw; but the rapid wearing out of the flexible band seems to have precluded this kind of multiplying wheel, as the jolting of cogs has done every other kind. Otherwise, Watt's sun-and-planet wheel affords an extremely simple contrivance for changing the reciprocating into a rotary motion making any number of turns, more or fewer than its own strokes.

STEAM HAMMER. One effect of that excessive division, not only of labour, but also of thought and attention, which, while it so multiplies machinery, tends to reduce the machine-users or even makers themselves to machines, is well exemplified in the still nearly universal instrument for making wrought iron, by subjecting the crude lumps of it, in a soft state, to the blows of a heavy hammer. Probably this *Helve-hammer*, as it is called, (see Iron, Sec. vi.) was, when contrived, the very best expedient then practicable for its purpose. Most contrivances of those times were so. It was preeminently a *practical* age, that age which could produce inventions without patents, and afford to bring to perfection such costly and difficult things as the *windmill*, which mathematicians, in trying to amend, found they could not imitate (including the *governor*, which Watt could not improve, but only translate into iron); the *ship* and the *sail*, whose mysterious perfections our science can neither improve nor explain; the ever weather-proof and unsinking *roofs*, the fire-proof and beautiful *church* and *galleries*, or the no less lovely and perfectly acoustic *chapter-hall* and preaching *baptistery;* and so many unimprovable contrivances, and not one for false or artificial wants. We must not imagine, while enjoying all these things, that because such inventions were not made for the purpose of enriching one person at the expense of all others, and were not continually superseding one another, the times were less inventive or less "practical" than ours. The helve-hammer will tell us quite a different story. Doubtless, then, it was the best means practicable,

to that practical age, of lifting and letting fall a heavy mass by a water-wheel. It would not be so now, for several reasons. We have ways open by the pressure-engine, &c., of storing and applying the *whole* water-power to lift it directly, and only as often as wanted, instead of a chance remnant of that power diverted to give first a rotary motion, and from this diverting at further loss a clumsy invariable hammering. But what has thus been barbarous, ever since the recognition of distinct laws of motion by Galileo, becomes in the highest degree absurd, now that steam-power takes the place of water. For the very first step—the action of the steam on the piston —gives the exact motion required, incomparably better than the final result on the hammer does. The piston is lifted and falls *vertically*, and with its *whole* weight (friction only deducted), because guided in a way that the hammer might just as easily have been. But because such guiding was impracticable in the age when the helve was invented, it must be lifted and fall in a circular *arc*, and with only about *a third* of its total weight. Moreover, the circular motion prevents its face and that of the anvil from being ever parallel when anything is between them, and they must be more inclined the thicker the object, and cannot be separated beyond a certain very limited distance; on approaching which thickness, an object so diminishes the fall of the hammer as to receive a very diminished effect from its blow. Yet a whole train of machinery must be interposed to change the motion of the *perfect* hammer, the piston, first into a rotary motion, and then again with blows and great loss into the motion of this most clumsy and *inferior* hammer; simply because the different links of the chain happen to be different men's trades, and we no longer regard trades as made for their work, but the work for them.

An engine-shaft being projected a few inches thicker than had previously been made, no hammer in England was capable of forging it; and the projectors having informed Mr. James Nasmyth of this, his attention was drawn to this specimen, perhaps an exceptional one in *machinery*, of the kind of practical wisdom that, in every other branch of our arts, he would probably have found the rule instead of the exception. The result was the speedy production of one of the most perfect of artificial machines, and noblest triumphs of mind over matter, that modern English engineers, we believe, have yet developed.

In the elevation on the steel plate annexed, *a* is the hammer, and *b* the anvil; the former fixed in the *hammer-block* F F, a mass weighing from 30 to 60 hundredweight, and the anvil similarly fixed in the *anvil-block* G G, large enough to resist by its *inertia* the whole blow from the falling mass, and so lose none of its impact, even should the ground below be yielding. The two *uprights* or *standards* A A form the guides to the ascent and descent of F F, but leave convenient space round the anvil, which is greatly deficient in all tilt-hammers. On the standards is fixed the *entablature* or lintel C, which also forms the base of the steam-cylinder D, and the passages into it, as seen sectionally at *f g* in the separate figure. Before these is fixed the *valve-box* J, enclosing the *slide* or *valve e* (small figure), whose rod or *spindle l l* ascends through a stuffing-box, and ends in a head or small piston *m* working in a small cylinder M, called the *steam-spring*. A small pipe *n* runs from the valve-chest up to this small cylinder M, and the consequence is, that whenever steam is admitted to J, it also has access to M, and keeps the slide *e* down in its lowest position till some greater force lift it against this *steam-spring*. When the steam from H is admitted to J by opening the *throttle* or *shut-off* valve in the box I (which is done by the rod *d*, and lever-handle also marked *d*, within reach of the attendant at Z), the slide-valve *e* is kept down so as to admit steam freely under the piston L and at once lift it, with the rod E and the suspended hammer. The bottom of E is enlarged, and buried in a cavity of the block F F, with several layers of hard wood, both below and above it, which are found elastic enough to prevent injury from the shocks, and the attachment is completed by keys *k* driven above this wood. The piston and hammer then are lifted until the position of the slide *e* shall be altered, which may be done by the attendant pressing down a lever *z*, which, by the long sliding rod S P P Q, draws down the *valve lever* R and lifts *l* against the steam-cushion in M. This, by cutting off the inlet passage *f* from the boiler, and opening it to *g*, which leads to the waste-pipe K and thence to the open air, will leave the piston unsupported, and allow the hammer to fall. But should this not be done, either by the above hand-gear or the machine itself, in the manner about to be described, the piston cannot be driven against the top of the cylinder, because it must first pass the holes *h h*, which, as soon as it is above them, will let out the surplus steam into a passage *i* leading to the waste-pipe K. At the same time these holes serve two other purposes, for as soon as the piston rises high enough to close them, the air above is shut in, and forms a cushion not only to protect the top of the cylinder from a blow, but, by its perfect elasticity, to send the piston down again with an addition to its weight, so that no momentum is lost, but all goes towards the impact on the anvil.

Let us now examine the self-acting gear which is to perform this change at any required point in the ascent of the hammer, thus letting it fall from any proposed height. The rod P P is capable, besides its up and down motion, of turning on its axis, by the attendant turning the winch of the short horizontal axle T ending in a bevel wheel Q, which turns a similar one seen on the said rod P, which it carries round by a projecting feather, while allowing it to slide freely up or down. Above this, a length of P, nearly equal to the range of the hammer, or of the piston, is seen to be screw-cut. Parallel to this, and a little nearer the hammer, is the perfectly similar screwed axle U, (partly hidden,) which however can only revolve, and not rise or fall. The two screws are seen to be right and left-handed, but in other respects just alike, and are coupled so as to turn

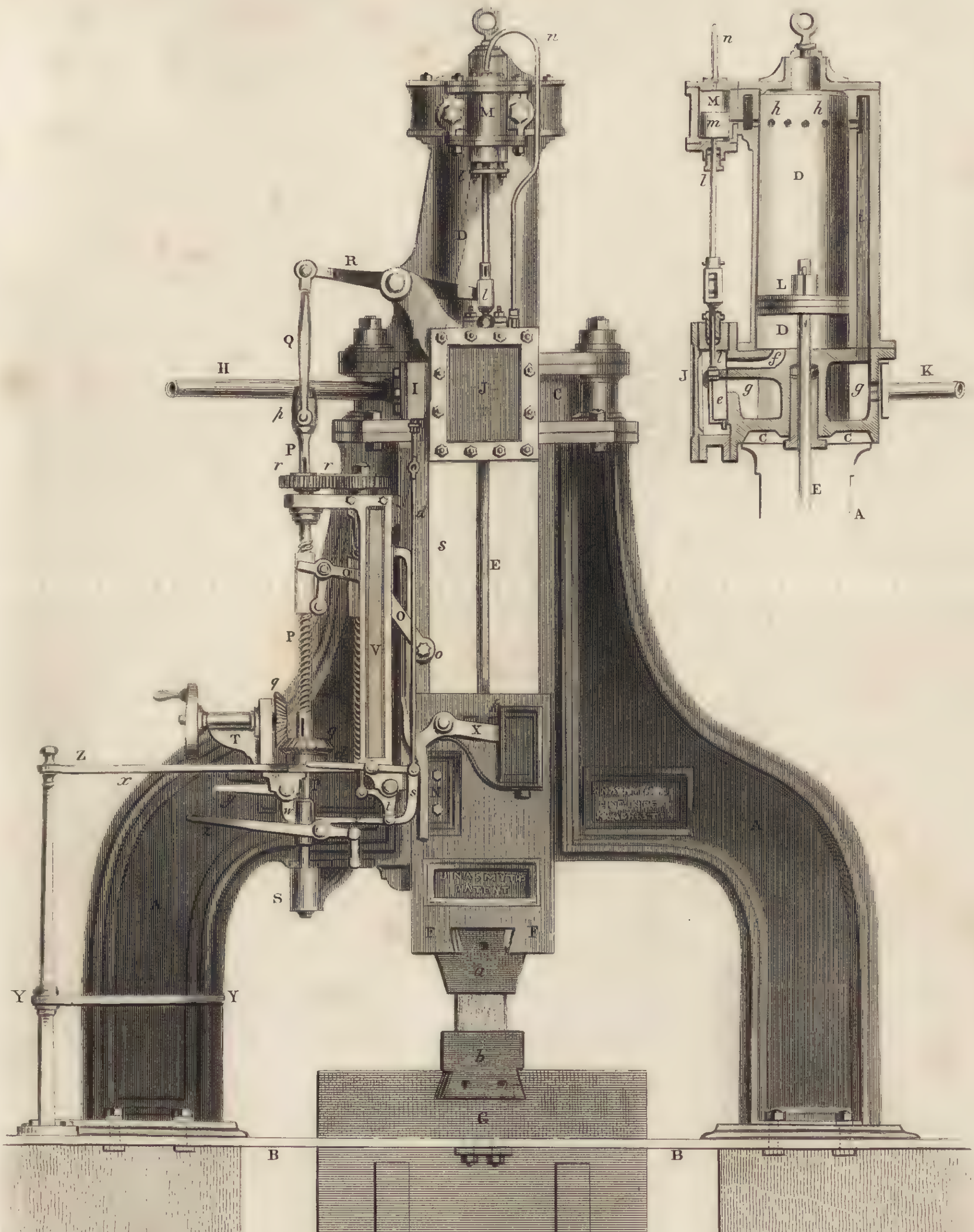
constantly together (contrary ways) by the two equal spur-wheels *r r*, one fixed on the top of U, the other on P, managed, like the bevel-wheel below, to turn with the axle, but not to rise or fall with it. On each screw is a nut; and these being prevented turning by the piece O connecting them, it is evident that when both screws are turned, by turning the winch at T, the two nuts will travel up or down exactly together, because the screws are equal. Now the piece O, connecting them, is part of a bent lever O O, whose fulcrum or pivot is attached to the nut of U, the partly hidden screw; and V, which hides it, is one of two guides to preserve the vertical motion of this nut. The end of all this is to carry the whole lever O O, by its fulcrum, bodily up or down, and, without change in its own posture, leave it at any required height. Its end *o* is a friction-pulley, and as the hammer-block rises, a *tappet* N fixed thereon must catch *o*, lift it, and keep it up much higher for the rest of the ascent. This cannot alter the place of the fulcrum-nut on U, and therefore depresses the other end of the lever, and with it the nut of P, to which it is jointed, and the whole of P bodily, drawing down Q and R, and lifting *l* and the slide valve, so as to shut off the access of steam, to let out that under the piston, and to drop it and the hammer, shortly after it has thus lifted *o*, whose height therefore regulates that of the fall. But this would not suffice to make the hammer self-acting, for in descending, it would again leave *o*, which would follow it down into the former position, raise P and Q, and again admit steam as at first, which after a certain amount of compression would stop the descent. If the hammer reached to strike a blow, it would not be with its full weight, and it might not strike at all, but only oscillate through a certain distance above and below *o;* its passing *o*, whether in rising or falling, being the cause of its stoppage and reversal soon after. A means of keeping P Q R down, then, when once depressed, is necessary for giving a full blow. This is furnished in the *trigger*, a small bent lever *y w*. The weight of its handle *y*, or a spring depressing that handle, keeps its point *w* pressed against P, which is hereabouts enlarged; and when the enlarged part gets below *w*, this catches on its shoulder, and keeps P down, and would do so indefinitely, until the attendant released it by lifting *y*. Thus a full blow is insured, but the rise of the hammer after it has struck, and preparatory to another blow, is made to depend on the attendant. To make the machine perform this, is the last and most ingenious part of its action. Observe, that it has to release the trigger *w*, not at the moment of coming down to any fixed point, (that would be easy,) but at the moment of *striking* whatever is placed on the anvil, however shallow or deep that may be. To make the release dependent on the fact of the *blow*, at whatever height that may take place, Mr. Nasmyth places, on the front of the hammer-block, a lever X, called from its shape tne *latch*. Its longer end would preponderate considerably, were it not supported by a spring behind the plate seen covering that end. Now the effect of the sudden shock of the blow is, to make this preponderate for a moment in spite of the spring. For, although the hammer and the block are arrested, the chief mass of the latch X is not so; but it persists in its downward course by *inertia*, which, added to its weight, overcomes the spring, (its weight alone not being sufficient for the purpose,) and compresses that spring a moment, until its elasticity drives it back. This little movement, although momentary, is made to re-admit steam to lift the hammer thus. A long upright bar *s s* (partly hidden by *d*) is connected at each end to V, by short and equal links, the lower of which is seen at *t*, so that V and *s s* resemble the two bars of a parallel ruler, the former fixed, and the latter capable of approaching to or receding from it, always parallel, and usually kept thrust forward by its lower end being bent to form the horizontal arm *v*, touching and kept forward by the trigger *w*. But at the moment of the blow, the above described kick of the latch X is given against whatever part of the bar *s s* it may be opposite to, and momentarily pushing back that whole bar, and therefore *v* and *w*, releases P, which immediately ascends or allows the valve-rod *l* to be pressed down by its steam-spring, and the steam readmitted to raise the piston and hammer. We know no other instance of an action in machinery being effected by the *inertia* of a body, the only force really applicable in this case.

It only remains to say, that the shock with which N strikes *o* is prevented from jarring the valve-gear, by P being connected with Q at *p*, in the same manner as the piston-rod E with the hammer-block, wood being interposed; and when the rods Q P are elevated to the position shown, an enlargement at the bottom enters a hollow fixed cylinder S, called the *buffer*, and is received by layers of leather.

The control over the hammer given by the handle *y* of the trigger, without readjusting the height of fall, is very perfect and useful; as, by keeping *y* up, the blows become all *stopped* by fresh steam intercepting each, so as either not to strike, or strike most gently; and on letting *y* drop, a full blow is given. A small nail, it is said, may be driven and neatly finished with repeated taps, or a nut cracked without injury to the kernel, by this mass, whose free descent will dash a 3-inch plank into splinters. No other machine, certainly not the smallest hand-hammer, is so brought under the thorough control, rather of the will than of the hands, or made so much like a part of the manager's self (obeying him like the pencil of the artist or the keys of the musician), as this Cyclops arm; which might squeeze into shape the largest celestial bolt in Europe, and has almost masticated rolls exceeding the heaviest lumps of the iron of space that our planet is known to have encountered.

STEARIC ACID—STEARINE. See Candle—Oils and Fats—Soap.

STEATITE, a soft magnesian mineral (*silicate of magnesia*—see Magnesium), unctuous to the touch, for which reason it is also termed *soapstone*. It is also known in Commerce as *French chalk*. Its sp. gr. is 2·65 to 2·8: its colour is usually greyish-green, but when worked and varnished, it becomes dark olive



NASMYTH'S PATENT STEAM HAMMER.

Copied by permission of the Inventor from the Machine in the Great Exhibition.

GEORGE VIRTUE, LONDON & NEW YORK

green. It occurs in beds generally associated with talcose slate. Like *potstone* and *serpentine*, which it nearly resembles in composition, it becomes considerably harder by exposure to the air. When first raised it may be easily turned with chisels: the turned articles may be polished, first with sand and water, and afterwards with tripoli and water, and, for the highest gloss, with rotten stone and oil, woollen cloths being used in each case. When the steatite has become hard, the methods employed for alabaster, as described under GYPSUM, may be resorted to. Steatite has also been named *figure stone*, in consequence of its having been used as the material for idols and other figures, which form the household gods of the Chinese: it was formerly supposed that they were made of a preparation of rice. The refractory nature of soapstone, and the facility with which it is worked, admit of its being cut into slabs for fire stones in furnaces and stoves, and for jambs for fire-places. It is also mixed with blacklead in the manufacture of crucibles. It is bored out for conveying water instead of lead pipes. It is an excellent material for kitchen-sinks, wash-tubs, bath-tubs, urinals, &c. It is readily wrought, and may be bored, turned, and planed by the ordinary tools of the carpenter, and it may be screwed together almost as easily as hard wood. It is used in the manufacture of porcelain: it makes the biscuit semi-transparent, but brittle. It forms a polishing material for serpentine, alabaster, and glass, and removes grease spots from cloth. It is ground into a powder and used for diminishing the friction of machinery. Dana states that soapstone is used in the United States for the sizing-rollers in cotton factories; in which case they are of large dimensions, such as 4½ feet long, and 5 to 6 inches in diameter. The advantages of soapstone as a material for baths and sizing-rollers, are, that it is not affected by the acid usually employed in sizing, and is not liable to warp, contract, or expand, by changes of temperature and moisture.

STEEL. See IRON, Sec. vii.

STEEL ENGRAVING. See ENGRAVING.

STEELYARD. See BALANCE, Fig. 89.—STATICS AND DYNAMICS.

STENCILLING. See PAPER-HANGINGS.

STEREOTYPE. See PRINTING, Sec. vi.

STILL. See DISTILLATION.

STOCKING. See WEAVING.

STONE. The art of *quarrying* or getting out stone from the earth, is one of great antiquity, coeval indeed with the art of erecting buildings of hewn stone. The excavation in the ground from which stone is extracted, is termed a *quarry*, from the circumstance that the stones are quadrated (*quarré*) or formed into rectangular blocks. Until the invention of gunpowder, the wedge and the hammer were the only tools used in working a quarry, but the introduction of that powerful mechanical agent greatly facilitated the operations of the quarry-man, and enabled him to get out enormous masses with comparative ease.

The implements used in quarrying are almost identical with those described under MINING, Sec. iii. and represented in Figs. 1164, 1165, and they consist of a *borer* or *jumping tool;* a *hammer* for striking it; a *scraper* for clearing the hole of the chips or pounded materials; a *claying bar* for driving in dry clay if the hole be too damp for the immediate introduction of the gunpowder; a long thin copper rod called a *needle*, which is driven into the charge while the hole is being *tamped*, or filled up, with the assistance of the *tamping bar*, with broken brick, pounded stone, &c., so that when the needle is withdrawn a channel is left for the insertion of the fuse.

In the ordinary practice of loading and firing the holes, the following steps are usually taken:—1. To dry out the bottom of the hole, if necessary, with small wisps of hay. 2. To pour in the gunpowder until it fills a certain number of feet or inches from the bottom of the hole. In a vertical or nearly vertical hole the powder will drop to the bottom; but if the hole be inclined, the powder should be scraped down with a wooden ramrod, although an iron scraper is often used. If the hole be horizontal, the powder is introduced by means of a scoop, and if it incline upwards, a cartridge is employed. 3. The needle is now introduced, with the point inserted well into the charge, and the handle or eye projecting above the hole at the top. 4. A little wadding of hay, straw, or turf, is put in over the powder. 5. Then comes the tamping, which may consist of small quarrystone and dust, unless it contain flinty particles, which strike fire, in which case broken brick may be used. The tamping is rammed down an inch or two at a time by means of an iron rod or tamping bar, the needle being frequently turned round to prevent its being fixed. 6. The last inch or two of the hole is filled up with damp clay. 7. The needle being carefully pulled out, the narrow opening left by it is filled with loose fine-grained powder (or with straws filled with powder), into the upper end of which is inserted a piece of touch-paper sufficient to burn half a minute: this being lighted fires the train and the charge: the quarrymen being in the meantime sheltered from the effects of the explosion. The touch-paper is made by soaking coarse paper in a strong solution of saltpetre or gunpowder, and then drying it.

The chief expense of quarrying is the boring of the holes necessary for the insertion of the charge. Where the rock is very hard, this is a slow and toilsome operation; and any practicable contrivance for facilitating it or for abridging the time required for its performance, would be a real improvement. In the granite quarries at Dalkey, near Dublin, it is stated that three men, two striking a 3-inch jumper, and one man holding and turning it after each stroke, were able to bore on an average 4 feet a day of holes, varying from 9 to 15 feet in depth; or with a 2½-inch jumper, 5 feet per day; with a 2¼ inch jumper, 6 feet per day; with a 2-inch jumper, 8 feet per day; with 1¾-inch jumper, 12 feet per day; and with a 1-inch jumper, for breaking the fragments of rock to smaller pieces, one man bored 8 feet per day. In these operations the waste of steel and iron was nearly as

follows:—a 3-inch jumper took for its bit 2 lbs. of steel, with which it would bore 16 feet, requiring to be dressed or sharpened 18 times: the waste of iron was 18 inches to each steeling, or $1\frac{1}{8}$-inch for each foot bored. The 2-inch jumper took $1\frac{1}{4}$ lb. of steel: the $1\frac{3}{4}$-inch jumper took $\frac{3}{4}$ lb. of steel: and the 1-inch jumper 3 oz. of steel. These jumpers would bore from 18 to 24 feet, with each steeling, and required to be sharpened about once for every foot bored. The weight of the hammers used with 3-inch jumpers was 18 lbs.: with $2\frac{1}{2}$ and $2\frac{1}{4}$-inch jumpers, 16 lbs.: with 2 and $1\frac{3}{4}$-inch, 14 lbs.: and with a 1-inch jumper, used by one man, a hammer of 5 to 7 lbs. was used.

Churn jumpers, so called from their mode of working, are from 7 to 8 feet long, with a steel bit at each end; their general diameter is $1\frac{1}{8}$ to $1\frac{1}{2}$-inch. Two men can bore about 16 feet per day with one of these jumpers. This form of jumper is more efficient than that which is struck on the head with a hammer. It is sometimes used with a spring rod and line. It is adapted to vertical or nearly vertical holes, and to rocks of moderate hardness. With granite the edge turns so rapidly, and the sharpenings require to be so often repeated, that the jumper and hammer are preferred. *Drilling* instead of boring the holes would greatly abridge the operation; but the cutting edges of the tools will not stand in any kind of stone.

"Upon the judicious selection of the position of the holes will, in a great measure, depend the useful effect of the blast; but two leading errors are committed by quarrymen or miners in general, viz. selecting an injudicious position for the charge, by which the action of the powder is exerted in the direction of the opening where it was introduced; and the adopting as a rule for the several charges, to fill a certain number of feet or inches of the hole bored, usually one-third of its depth, instead of employing given weights adapted to the *lines of least resistance*. The line of least resistance is that line by which the explosion of the powder will find the least opposition to its vent in the air. This need not necessarily be the shortest line to the surface; as, for instance, a long line in earth may, from the same charge, afford less resistance than a shorter line in rock. Supposing the matter in which the explosion is to take place to be of uniform consistence in every direction, charges of powder to produce similar proportionate results ought to be as the cubes of the lines of least resistance, and not according to any fanciful depth of hole bored. Thus, if 4 oz. of powder would have a given effect upon a solid piece of rock of 2 feet thick to the surface, it ought to require $13\frac{1}{2}$ oz. to produce the same effect upon a piece of similar rock 3 feet thick; that is, as 8 (cube of 2 feet line of least resistance) is to 4 (charge of powder in ounces), so is 27 (cube of 3 feet line of least resistance) to $13\frac{1}{2}$ (charge in ounces); or what is the same thing, half the cube of the line of least resistance expressed in feet will, on this particular datum, be the charge in ounces, as follows:—

Line of Least Resistance in feet.	Charge of Powder. lbs.	oz.
1	0	$0\frac{1}{2}$
2	0	4
3	0	$13\frac{1}{2}$
4	2	0
5	3	$14\frac{1}{2}$
6	6	12
7	10	$11\frac{1}{2}$
8	16	0

These quantities being common, merchant's blasting powder will be found adequate for any rock of ordinary tenacity; but a precise datum should be ascertained by a few actual experiments on the particular rock to be worked. Thus, with a 2-feet line of least resistance, A to B, Fig. 2080, it should be ascertained whether 4 oz , 6 oz., or 8 oz. are requisite to produce a good effect; with 3-feet line of resistance, whether $13\frac{1}{2}$ oz., or 18 oz., or 27 oz., &c. On the results of these trials a scale may be adopted for guide in the service."[1] If the charge be judiciously disposed, there will be only a trifling report, and the mass of rock will be lifted, and thoroughly fractured, rent, or thrown over, without being forcibly projected; whereas, in the common mode of blasting, a loud report is heard, louder in proportion to the less useful effect produced, and fragments of stone are scattered about to a considerable distance.

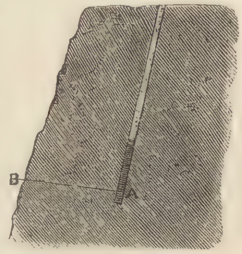


Fig. 2080.

There is an economy, both in labour and powder, by establishing on the rock an exposed front either vertical or horizontal, for in such case a line of least resistance can be obtained in a different direction from that of the hole bored, as A B, Fig. 2080; for it must be obvious that if the action of the powder be exerted in the direction of the hole bored, a part of the explosion finds comparatively easy vent by that opening in spite of the best tamping, and is wasted; whereas if the explosion be forced through another direction, the whole of its power is beneficially exerted.

In stratified rocks and close parallel beds and seams it will be found much easier, and the effect more advantageous, to bore the holes in the direction of the joints, and to place the powder as at A, Fig. 2081;

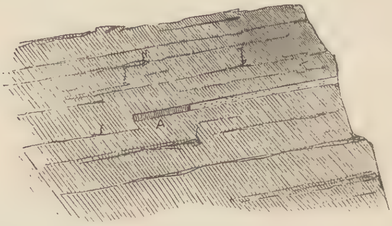


Fig. 2081.

(1) Sir John Burgoyne, K.C.B., &c., "On the Blasting and Quarrying of Stone for Building, and other purposes;" published among the "Professional Papers of the Corps of Royal Engineers," and also in a separate form in Weale's Rudimentary Series.

this will have more effect in lifting large masses than if placed across the grain.

It is of importance to be able to ascertain readily the space occupied by any given quantity of powder. The following table, by Major-Gen. Sir Charles Pasley, K.C.B., calculated for round holes of different sizes from 1 to 6 inches, will be found useful:—

Diameter of the hole.	Powder contained in one inch of hole.		Powder contained in one foot of hole.		Depth of hole to contain 1 lb. of Powder.
Inches.	lbs.	oz.	lbs.	oz.	Inches.
1	0	0·419	0	5·028	38·197
1½	0	0·942	0	11·304	16·976
2	0	1·676	1	4·112	9·549
2½	0	2·618	1	15·416	6·112
3	0	3·77	2	13·24	4·244
3½	0	5·131	3	13·572	3·118
4	0	6·702	5	0·424	2 387
4½	0	8·482	6	5 784	1·886
5	0	10·472	7	13·664	1·528
5½	0	12·671	9	8·052	1·263
6	0	15·08	11	4·96	1·061

The gunpowder used for the blasting of rock is inferior in strength to that used for sporting or for the army and navy; it is a cheaper and coarser powder, and is preferred on the supposition that, by igniting more slowly, the power is applied more forcibly and efficiently than by the rapid shock of powder of superior quality, such as must be used for impelling projectiles. This appears to be a mistake, and there is little doubt that the sudden and violent shock of superior powder would produce more extensive cracks in the rock, which is the great object to be attained, than the slower action of merchant's blasting powder. Indeed, the success of gun-cotton, so far as it has been applied in quarrying, seems to prove that a sudden violent action far more rapid than that of the best gunpowder, performs the largest amount of useful work upon the rock. It appears, also, from some experiments by Sir J. Burgoyne, given in the work already quoted, that about 9 parts of Government powder are equal to 13 of the merchant's powder, and that it would be good policy to employ stronger powder for blasting, even at increased prices. The fine-grained powder made by Government for the Rifle Service and by manufacturers for shooting, would be too costly an article, but it is considered that the best *cannon* powder might be used with advantage. The cost of blasting powder in the country is from 2*l.* 10*s.* to 3*l.* 10*s.* per 100 lbs.; but powder similar to the Government cannon powder might be sold at between 2*l.* 10*s.* and 3*l.* Good Government cannon powder contains 75 per cent. of nitre, and 25 of sulphur and charcoal. [See GUNPOWDER.] Merchant's blasting powder contains from 66 to 73 of nitre, and from 24 to 32½ of sulphur and charcoal, together with impurities.

The quarrymen are so impressed with the idea of the advantage of the gradual ignition of the gunpowder used in blasting, that it has even been recommended to mix therewith a quantity of fine, dry sawdust of elm or beech, in the proportion of ⅓d of sawdust for small charges, and ½ for large, and it is asserted that this mixture will produce as good results as equal quantities of gunpowder alone. The action of the sawdust, by dividing the particles of the charge, and causing them to ignite more gradually, is said to be the production of greater force on the rock than by the more sudden explosion. Those who advocate this proceeding would, we should suppose, contend that an ounce weight striking a body 16 times with a certain velocity would have the same, or even a greater effect, than a weight of 1 pound striking the body with the same velocity. The power of the charge is also said to be improved by mixing about ¼ of quicklime with the powder, on the principle that it will absorb any moisture that may be in the powder. If such really be the effect, the absorption of water by the lime would lead to the evolution of heat, and cause the sulphur and the nitre to react on each other, and lead to the formation of sulphate of lime. Neither this practice nor the former would be adopted by any one acquainted with the merest elements of mechanical and chemical science. It is also stated that if a hollow space be left above the charge a greater effect will be produced than if the tamping be continued down to the charge. For example, in two similar holes the charge C, Fig. 2082, with a hollow space *s* over it, is said to produce as

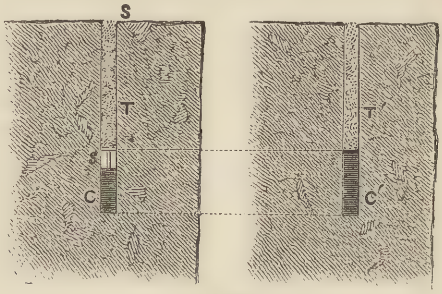


Fig. 2082.

good an effect with ½ or ⅔ds the quantity as the full charge C′, provided the tamping T, from *s* to S, be as good and as deep as that at T′. On this point Sir John Burgoyne remarks, that "an increased effect will certainly be produced by such hollow, in the same manner as with guns, which are frequently burst by the occurrence of a hollow between the powder and the shot, but there must be great reason to doubt its *practical* utility. No accounts are given of the well-defined result of actual experiment, nor are any rules attempted to be laid down for the extent of the hollow spaces in proportion to the quantity of powder in the charge, &c., to produce useful effect; and yet these must be matters of consequence; nor is it anywhere stated that it has ever been practically continued to be used, notwithstanding the great saving of powder professed to arise from the adoption of this principle. In large charges, the space that could be left would be too small to produce any useful effect; and in small charges, the more simple, quick, and cheap way would be, by using the full charge of powder."

With respect to the quantities of powder used at a blast, the practice varies. In working quarries for large stones large blasts are often used. Thus in the Kingstown quarries, where granite stones for ashlar

work are squared to from 40 to 60 cubic feet each, 50, 60, and 70 lbs. of powder are frequently exploded in a single blast, in some cases filling $\frac{2}{3}$ds of a hole of 4 or $3\frac{1}{2}$ inches diameter, and 20 feet deep. With such a charge a mass of 1,200 cubic yards, or 2,400 tons, has been brought down or thoroughly shaken and rent. At Gibraltar, where the rock is a peculiarly hard limestone marble, large masses are brought down by the military miners under the Royal Engineers, by boring holes about 9 feet deep, with $2\frac{1}{2}$-inch jumpers, the charge being 4 lbs. of powder: the explosion has no apparent effect; nevertheless, the rock is shaken below: the needle hole is cleared out, and the hole again filled, the charge being from 8 to 12 lbs.; it is fired again, and the process is repeated with a third charge of from 20 to 30 lbs.: a fourth charge may even be fired, and in this way the rock is greatly separated, and rent to the extent of 10, 20, or 30 feet in different directions. This plan is said to waste less powder than the former, and to produce a less violent projecting of stones.

Sir John Burgoyne recommends that greater precision be introduced into the practice of blasting, which is usually conducted in a slovenly manner. He would allot every charge by weight according to a scale adapted to lines of least resistance or to the circumstances of the case. The overseer or powderman should be provided with a strong copper canister containing from 3 or 4 lbs. to 10 or 12 lbs. of powder, with a large mouth or opening, secured by a well-fitting cover from spilling, accident, or weather, and with a lock and key. Also a set of marked copper measures of the capacity of 1 lb., 4 oz., and 1 oz.: a copper cylindrical tube of 3 feet or $3\frac{1}{2}$ feet long by $\frac{3}{4}$ inch diameter; a set of 3 tubes of about 1 inch in diameter, each 3 feet long, with joints to admit of being screwed into one length of 6 or 9 feet, or with a larger number of joints if deeper holes be employed, so that when put together the interior may form one smooth surface. There should also be a copper funnel, with the bowl large enough to contain about 1 lb. of powder, and the neck 2 inches long, and about $\frac{3}{4}$ inch diameter. By means of this funnel and the tubes, the charge of powder may be lodged clear to the bottom of the hole, and if horizontal, or nearly so, by pushing it in through the tubes with a wooden stick or ramrod. With these precautions none of the grains of powder hang about the sides of the hole, which is a source of danger in the ordinary method. The charge having been deposited, one end of a piece of patent fuse is inserted well into the powder, and the other end is cut off about an inch beyond the outside of the hole: a little wadding is then pressed down over the powder with the tamping-bar, and upon that the tamping without any moist clay. The first blows of the tamping-bar over the charge often lead to its ignition: to prevent this, the first 2 or 3 inches of the tamping should be merely pressed down gently over the wadding, and the hard ramming commenced over that. It would be desirable if the tamping-bar were tipped with brass. The tamping being completed, the end of the fuse is lighted, and with these precautions the explosion takes place with more certainty, and the whole operation is attended with less danger than by the old method.

Bickford's *miners' safety-fuse* is a great improvement on the old method of laying the trains and firing the charge. It is a cylinder of gunpowder or other explosive compound enclosed within a hempen cord, which is first twisted and afterwards overlaid with another cord for the purpose of strengthening the casing thus formed: it is next varnished in order to preserve the contents from moisture, and it is lastly covered with whitening to prevent the varnish from adhering. This fuse can be used in damp situations, and even under water. In wet quarries, or where wet joints are met with in boring, and the holes fill with water, the usual plan is to stop the leaky joints in the hole by means of a paste of fine clay; but with the safety-fuse the charge is put into a water-proof bag, a length of fuse is closely tied in its mouth, and the bag being pushed home to the bottom of the hole, the tamping is completed, and the charge is fired with as much certainty and effect as in dry work. This fuse burns at the rate of from 2 to 3 feet per minute. Charges of powder are in some cases fired by means of a voltaic battery, for which purpose a platinum wire is buried in the charge, and from each end of this wire a copper wire proceeds to the battery. On closing the circuit the platinum wire becomes red-hot, and ignites the gunpowder.

A great variety of opinions have been expressed on the subject of tamping. The object of this operation is to obtain the greatest possible resistance over the charge of powder, and if the tamping could be made as strong as the rock itself it would be perfect. The materials used in tamping are the chips and dust of the quarry, unless it contain flint, such as would strike fire with the tamping-bar. Fine and dry sand is used in some places, or dried or baked clay, or broken brick, or vegetable earth. It has been found, by experiment, that clay dried to a certain extent forms, on the whole, the best tamping material. Broken brick, tempered with a little moisture during the operation, is the next best material. It has been stated that, by pouring in fine dry sand, stirring it up as it is poured in, in order to make it more compact, the slow and dangerous operation of driving in the tamping may be dispensed with. It appears, however, from a number of experiments, the results of which are given by Sir John Burgoyne, "that sand of any description, and however applied, is, when used by itself, and for small blasts, perfectly worthless, and quite inferior to clay tamping for larger explosions, at least so far as for holes 9 feet deep by $2\frac{1}{2}$ inches in diameter."

Attempts have been made to increase the resistance by fixing some kind of plug or wedge in the loaded hole. A conical piece of iron placed immediately over the charge, before the tamping is filled in, was found to give a great increase of resistance, as was also a barrel-shaped plug driven in over the tamping. Captain Norton concludes, from some recent experiments, that a plug of deal placed over the powder, of the

same dimensions as the bore, and about 3 or 4 inches long, adds greatly to the force of the charge.[1]

In the operation of blasting the blocks are broken irregularly, and the stone is wasted. Hence a more economical method is often employed for getting out the stone. Stone which occurs in contiguous strata presents a number of contact surfaces, or *planes of cleavage*, and the stone is more easily divisible in lines parallel to these cleavage planes than in any other direction: these lines form what is called the *cleaving grain* of the stone. In order, therefore, to separate a large block, a number of iron wedges are placed in line a few inches apart on the natural face of the rock, and in the direction of the cleaving-grain, and they are driven into the stone with heavy sledges until a part is loosened: a channel is then cut in the direction of the length of the intended block, and at a distance from the natural edge of the stone equal to its required breadth. The wedges are placed in the channel, and driven until the stone is split in that direction also. In very hard stones the wedges are not placed in the channels, but in *pool-holes* sunk in the direction in which the block is to be separated from the mass. A similar operation is performed in the direction of the breadth of the block, and in this way a large portion is detached from the original mass. The blocks are next reduced to a rectangular form by means of a *kevel*, a tool pointed at one end and flat at the other, with which the irregular parts are chipped off. The blocks are then, by means of movable cranes, raised upon trucks or low carriages, and drawn on iron railways to the quays or wharfs where the stone is shipped.

At the granite quarries of Rubieslaw, near Aberdeen, which the Editor visited in the autumn of 1852,[2] masses of rock are detached by boring and blasting. The bores are often as much as 12 to 16 and even 18 feet deep, and $2\frac{1}{2}$ inches diameter. The first firing loosens a very large quantity of rock. The perpendicular cracks or fissures caused by this operation are filled with gunpowder and fired, by which means the mass is shifted several inches from its bed, and even thrown some yards forward. This operation is called *bulling*. The rock is cut up into scantlings by wedges as above described; but when the block is very deep the cutting is performed by *plug and feather*. The *feathers* are inverted wedges with circular backs for fitting the holes, the opposite sides being plain. The holes bored are about $1\frac{1}{4}$ inch in diameter, 5 or 6 inches deep, and in a row 6 inches apart. Two feathers are put into each hole, and between the feathers long wedges are introduced and driven until the block opens in the required direction. [See GRANITE.] A large proportion of the work of this quarry consists in working up road metal for the streets of London. There are various kinds of paving stones, such as *common sixes*, so named, because as they lie in a pavement their depth is only 6 inches: the superficial extent of each stone is about 10 inches by 6. As the stones increase in size they are called respectively *half-sovereigns*, *sovereigns*, *cubes*, and *imperials*. The freight to London is about 8*s*. per ton, and the vessels which convey the stones take in ballast at London, and then, repairing to Sunderland, receive at that port coals for Aberdeen; by which means coals are sold in Aberdeen about 5 per cent. cheaper than if no granite were transported by the same shipping, and consequently the paving-stone is afforded cheaper in London than if no coals were conveyed to Aberdeen. The cost of paving-stone is about 13*s*. per ton, which, with the freight and incidental charges, raises the price in London to about 24*s*. per ton. The stones are weighed in the quarry by a very primitive kind of steelyard, called a *Dutch-back weighing machine*. The following engraving is from a sketch made in the quarry by our

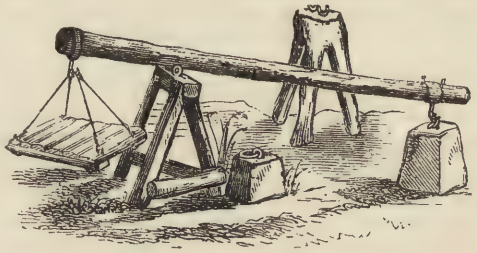


Fig. 2083. DUTCH-BACK WEIGHING MACHINE.

travelling companion, Mr. Hatcher. The length of the short lever is 3 feet 8 inches, and of the long lever 11 feet. The stone weight is equal to 5 cwt.

The various methods of working and dressing building stones are described under their respective titles in this work. [See MASONRY—GRANITE—SANDSTONE, &c.] We have, however, been lately informed of some particulars respecting the sandstone of Edinburgh, which may be noticed in this place. The sandstone of which the Scottish capital is built has long been in evil repute for producing diseases in the lungs of the masons who work it. The hardness of the stone requires much chiselling, and causes it to yield a fine irritating powder. Our informant[3] says:—"I have fallen in with the foreman of the masons who built the Scott monument. He is an intelligent trustworthy person, and he gave me the following particulars:—The mortality among stone-hewers from affections of the lungs is notorious in the trade. It is very rare to see a hewer who has reached the age of 50, and not uncommon, on the other hand, to see men who began to hew at 16 dead at 24. Many die about 35. Builders are as long-lived as their neighbours of other callings. My informant knew several who had reached the age of 70. The disease of the lungs, which is so mortal, is called by the sufferers them-

(1) A description of Captain Norton's Percussion Blasting Cartridge will be found in the Mechanic's Magazine, No. 1553.

(2) The Editor takes this opportunity of offering his acknowledgments to Mr. William Hay, the intelligent foreman of the quarry.

(3) Dr. George Wilson, of Edinburgh. Most of our readers are aware of the deservedly high scientific reputation of this gentleman; his friends only are aware of his unwearied activity in promoting the happiness, and alleviating the sufferings of his fellow creatures. We have been indebted to Dr. Wilson for information and assistance in this work, which in several cases we have not been permitted to acknowledge; nor would this note be allowed to appear if our friend had to correct the proof-sheet of his contribution.

selves, emphatically, 'the mason's trouble,' which means, simply, 'the mason's disease;' the word *trouble* being constantly used in homely Scotch as equivalent to disease. Masons in the country suffer less from it than those in town, because the former build as well as hew, whilst the latter either solely build or solely hew. Carvers or sculptors suffer more than rough hewers, and the hardest stones induce the disease most quickly. In illustration of this my informant referred to Craigleith stone, (a very pure sandstone,) as so much harder than Binnie stone, (also a sandstone,) that a man who could chisel 15 linear feet of the latter in a day, could only chisel 6 of the former. Craigleith sandstone has always had an evil notoriety as the most prejudicial to the hewers of the Edinburgh building stones; and my informant, like all the masons I have talked to on the matter, imputed its noxiousness to the large quantity of sulphur in it. Like most sandstones, it does contain a very small proportion of sulphuret of iron, but I need not say that it is the fine siliceous powder that does the mischief. My informant confirmed this by his statement, that when a row of men were working together under a shed or wooden hoarding, so great a cloud of sandstone-powder was raised, that you could not, standing at one end of the row, see the men at the other. Quarry-men, he added, suffered less than masons hewing under cover, because they worked in the open air.

"The mason's trouble, no doubt, includes several diseases. It begins with efforts to clear the throat and a short unfrequent cough. Difficulty of breathing soon follows, much expectoration, frequently spitting of blood, and in the end hopeless consumption. Some linger for 18 months or more after being laid aside from work. Most of them reach the grave much more quickly: and medical men would no doubt give different names to the affection of the lungs occasioning death in different cases; but local irritation, ending in organic disease of some portion of the breathing apparatus, would be the history of nearly all. Seventy men were under my informant at the Scott monument, and during the 4 years which its building occupied, 18 men, according to him, died of the mason's trouble.

"By the advice of Dr. Alison some of the men wore wire respirators, but they did not altogether exclude the stone-dust; and he did not observe that they did any good. He had heard that the German stone-masons, who wear their beards, did not suffer as his countrymen did; but he understood also that they worked in the open air, and he thought that that, probably as much as the moustaches, kept them well. The Liverpool masons are now wearing their moustaches, as are also the men in some of the Glasgow engine foundries.

"So coolly do our masons contemplate their fate, that when one of their number is compelled by the mortal disorder to give up work, they speak of him as having 'gone to grass,' and when he dies they raffle his tools at one of the Freemason's lodges for the benefit of his widow. My informant seemed to think it a matter of course that a mason must leave a widow."

Together with this information our kind correspondent sent us a respirator recently invented by the Rev. Mr. Nisbet of Canongate, Edinburgh. It is sold for 2*s*. by Messrs. Blackhall & Scott, Comb-makers of Edinburgh. We have endeavoured to represent it in Fig. 2084. It consists of a piece of horn adapted to the curvature of the mouth, perforated with a number of vertical slits, covered on the outside with a single layer of black cloth, which serves to filter the air, and prevent the particles of stone

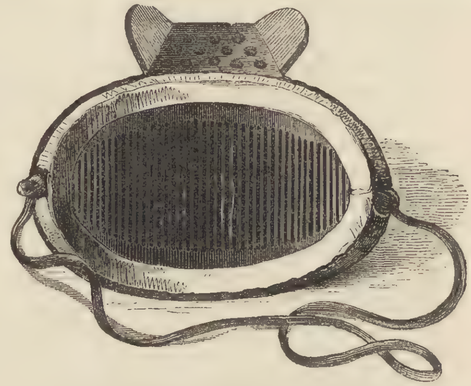


Fig. 2084. RESPIRATOR FOR MASONS.

passing through. It is bordered on the concave or inner side with a ridge of thick leather, which, with an elastic band passing round the head, serves to retain the little instrument close to the mouth. For the protection of the nostrils, there is, projecting from the top part, a flat piece of horn perforated with holes, and also covered with cloth on the outside: on each side of this perforated horn, a flat piece of horn is attached so as to enclose a large portion of the nose. This respirator is used by millers and colliers as well as by masons, but not largely by any. A simpler respirator is made without a nose-piece.

We now return to the more immediate object of this article. The choice of a stone for building purposes is of very great importance, and, until recently, had not been directed by scientific principles. Most of our public buildings are hastening to decay in consequence of the decomposition and disintegration of the stones of which they are composed. The selection of a stone which will resist the action of a smoky atmosphere of varying degrees of moisture, of wind, and dashing rain, of frost, and other meteoric causes, becomes therefore a matter of high consideration. And it was a wise proceeding on the part of Her Majesty's Commissioners of Woods and Forests, previous to the erection of the new Houses of Parliament, to appoint a scientific commission[1] to inquire into the qualities of the various stones used in Great Britain for building purposes, with a view to the selection of a hard, tenacious, and compact material for the new Palace at Westminster. We propose to give a brief abstract of the Report made on the occasion.

(1) The Commissioners were Mr. Barry, Sir H. T. de la Beche, Dr. W. Smith, and Mr. C. H. Smith. The specimens of stones collected were submitted to tests both mechanical and chemical, by Professors Daniell and Wheatstone, of King's College, London

The Commissioners did not consider it necessary to extend their inquiries to granites, porphyries, and other stones of similar character, on account of the great expense of working them in decorated edifices, and from a conviction that an equally durable, and in other respects a more eligible material, could be obtained for the object in view from among the limestones or sandstones of the kingdom.

The Commissioners soon had striking proofs of the necessity and importance of this inquiry in the lamentable effects of decomposition observable in the greater part of the limestone employed at Oxford: in the magnesian limestones of the minster, churches, and other public edifices at York, and in the sandstones of which the churches and other public buildings at Derby and Newcastle are constructed; and numerous other examples. The unequal state of preservation of many buildings often produced by the varied quality of the stone employed in them, although it may have been taken from the same quarry, showed the propriety of a minute examination of the quarries themselves, in order to gain a proper knowledge of the particular beds from whence the different varieties have been obtained. An inspection of quarries was also desirable for the purpose of ascertaining their power of supply and other important matters; for it frequently happens that the best stone in quarries is often neglected, or only partially worked, in consequence of the cost of laying bare and removing those beds with which it may be associated; whence it happens, that the inferior material is in such cases supplied.

The stones used in building are named either from the places where they are quarried, or from the chief ingredients of their composition. The term *freestone* is applied indefinitely to that kind of stone which can be wrought with the mallet and chisel, or cut with the saw. It includes the two great divisions of *limestone* and *sandstone*. The limestone of Portland has long been used in the metropolis, but other kinds are also employed.

Sandstones are generally composed of either quartz or siliceous grains, cemented by siliceous, argillaceous, calcareous, or other matter. Their decomposition depends on the nature of the cementing substance, the grains being comparatively indestructible. With respect to limestones composed of carbonate of lime, or the carbonates of lime and magnesia, either nearly pure or mixed with variable proportions of foreign matter, their decomposition also depends upon the mode in which their component parts are aggregated; those which are most crystalline being found to be the most durable, while those which partake least of that character suffer most from exposure to atmospheric influences. The various limestones termed *oolites* or *roestones*, are composed of oviform bodies cemented by calcareous matter of a varied character: they suffer unequal decomposition unless such oviform bodies and the cement be equally coherent and of the same chemical composition. The limestones termed *shelly*, from their being formed of broken or perfect fossil shells, cemented by calcareous matter, suffer unequal decomposition, in consequence of the shells, which are mostly crystalline, offering the greatest amount of resistance to the decomposing effects of the atmosphere.

Sandstones, from the mode of their formation, are frequently laminated, especially when *micaceous*, the plates of mica being generally deposited in planes parallel to their beds. Hence if such stone be placed in buildings with the planes of lamination in a vertical position, it will decompose in flakes, according to the thickness of the laminæ; whereas if it be placed so that the planes of lamination be horizontal, or as in its natural bed, the amount of decomposition will be comparatively immaterial. Limestones used in building are not liable to the kind of lamination observable in sandstones; but there are some varieties, chiefly of shelly limestone, which have a coarse laminated structure generally parallel to the planes of their beds, and such stones should be placed in buildings with the planes of lamination horizontal.

The chemical action of the atmosphere produces a change in the entire matter of the limestones and in the cementing substance of the sandstones, according to the amount of surface exposed. The mechanical action due to atmospheric causes, occasions either a removal or a disruption of the exposed particles, the former by means of powerful winds and driving rains, and the latter by the congelation of water forced into or absorbed by the external portions of the stone. These effects are reciprocal, chemical action rendering the stone liable to be more easily affected by mechanical action, which latter, by constantly presenting new surfaces, accelerates the disintegrating effects of the former. Buildings in this climate are generally found to suffer the greatest amount of decomposition on their southern, south-western, and western fronts, from the prevalence of winds and rains from those quarters; so that stones of great durability should be employed in fronts with such aspects. As an instance of the difference in degree of durability in the same material subjected to the effects of the atmosphere in town and country, the Commissioners notice the several frustra of columns and other blocks of stone that were quarried at the time of the erection of St. Paul's Cathedral in London, and which are now lying in the Isle of Portland, near the quarries from whence they were obtained. These blocks are invariably found to be covered with lichens, and although they have been exposed to all the vicissitudes of a marine atmosphere for more than 150 years, they still exhibit, beneath the lichens, their original forms, even to the marks of the chisel employed upon them; whilst the stone that was taken from the same quarries and placed in the cathedral itself, is in those fronts which are exposed to the south and south-west winds found in some instances to be fast mouldering away. *Colour* is of more importance in the selection of a stone for a building to be situated in a populous and smoky town, than for one to be placed in an open country where all edifices usually become covered with lichens; for although in such towns those fronts which are not exposed to the prevailing winds and

rains will soon become blackened, the remainder of the building will constantly exhibit a tint depending on the natural colour of the material employed.

Buildings which are highly decorated, such as the churches of the Norman and Pointed styles of architecture, afford a more severe test of the durability of any given stone, all other circumstances being equal, than the more simple and less decorated buildings, such as the castles of the 14th and 15th centuries, inasmuch as the material employed in the former class of buildings is worked into more disadvantageous forms than the latter as regards exposure to the effects of the weather. Buildings in a state of ruin, from being deprived of their ordinary protection of roofing, glazing of windows, &c., constitute an equally severe test of the durability of the stone employed in them.

The durability of various building stones in particular localities, was estimated by examining the condition of the neighbouring buildings constructed of them. Among sandstone buildings were noticed the remains of Ecclestone Abbey, of the thirteenth century, near Barnard Castle, constructed of a stone closely resembling that of the Stenton quarry, in the vicinity, in which the mouldings and other decorations were in excellent condition. The circular keep of Barnard Castle, apparently also built of the same material, is in fine preservation. Tintern Abbey is noticed as a sandstone edifice, that has to a considerable extent resisted decomposition. Some portions of Whitby Abbey are fast yielding to the effects of the atmosphere. The older portions of Ripon Cathedral; Rievaulx Abbey; and the Norman keep of Richmond Castle in Yorkshire, are all examples of sandstone buildings in tolerably fair preservation. Of sandstone edifices in an advanced state of decomposition are enumerated Durham Cathedral, the churches at Newcastle-upon-Tyne, Carlisle Cathedral, Kirkstall Abbey, and Fountain's Abbey. The sandstone churches of Derby are also extremely decomposed, and the church of St. Peter at Shaftesbury is in such a state of decay that some portions of the building are only prevented from falling by means of iron ties.

The choir of Southwell Church of the 12th century affords an instance of the durability of a magnesio-calciferous sandstone after long exposure to the influences of the atmosphere. The Norman portions of this church are also constructed of magnesian limestone similar to that of Bolsover Moor, and which are throughout in a perfect state, the mouldings and carved enrichments being as sharp as when first executed. The following buildings also of magnesian limestone are either in perfect preservation or exhibit only slight traces of decay: the keep of Koningsburgh Castle; the church at Hemingborough of the fifteenth century; Tickhill Church of the same date; Hudderstone Hall of the sixteenth century; Roche Abbey of the thirteenth century. The magnesian limestone buildings which were found in a more advanced state of decay, were the churches at York, and a large portion of the Minster, Howdon Church, Doncaster Old Church, and buildings in other parts of the country, many of which are so much decomposed, that the mouldings, carvings, &c., are often entirely effaced.

The Report speaks in high terms of the preservation of buildings constructed of oolitic and other limestones: such are Byland Abbey of the twelfth century; Sandysfoot Castle, near Weymouth, constructed of Portland oolite, in the time of Henry VIII; Bow-and-Arrow Castle, and the neighbouring ruins of a church of the fourteenth century in the island of Portland. The oolite in the vicinity of Bath does not seem to wear well.

The excellent condition of the parts which remain of Glastonbury Abbey, shows the value of a shelly limestone similar to that of Doulting; whilst the stone employed in Wells Cathedral, apparently of the same kind, and not selected with equal care, is in parts decomposed. In Salisbury Cathedral, built of stone from Chilmark, there is evidence of the general durability of a siliciferous limestone; for, although the west front has somewhat yielded to the effects of the atmosphere, the excellent condition of the building generally is most striking.

The materials employed in the public buildings of Oxford afford a marked instance both of decomposition and durability; for whilst a shelly oolite, similar to that of Taynton, which is employed in the exposed parts of the more ancient parts of the Cathedral, in Merton College Chapel, &c., is generally in a good state of preservation, a calcareous stone from Heddington, employed in nearly all the colleges, churches, and other public buildings, is in such a deplorable state of decay as, in some instances, to have caused all traces of architectural decoration to disappear, and the ashlar itself to be in many places deeply disintegrated.

In Spofforth Castle, two materials, a magnesian limestone and a sandstone, have been employed, the former in the decorated parts, and the latter for the ashlar; and although both have been equally exposed, the magnesian limestone has remained as perfect in form as when first employed, while the sandstone has suffered considerably from the effects of decomposition. In Chepstow Castle, a magnesian limestone is in fine preservation, and a red sandstone rapidly decaying. A similar result was observed in Bristol Cathedral, which afforded a curious instance of the effects of using different materials; for a yellow limestone and a red sandstone have been indiscriminately employed, both for the plain and the decorated parts of the building; not only is the appearance unsightly, but the architectural effect of the edifice is also much impaired by the unequal decomposition of the two materials.

Preference is given in the Report to the limestones on account of their more general uniformity of tint, their comparatively homogeneous structure, and the facility and economy of their conversion to building purposes; and of this class preference is given to those which are most crystalline. Professor Daniell's opinion was that the nearer the magnesian limestones approach to equivalent proportions of carbonate of

lime and carbonate of magnesia, the more crystalline and better they are in every respect. It was considered that this crystalline character, together with durability, as instanced in Southwell Church, &c.; uniformity in structure; facility and economy in conversion; and advantage in colour, were all comprised in the magnesian limestone or dolomite of Bolsover[1] Moor and its neighbourhood, and was accordingly recommended as the most fit and proper material to be employed in the new Houses of Parliament. This opinion was based upon a large number of experiments upon the specimens of the stones of the various quarries visited by the Commissioners. The specimens as delivered to them were in the form of 2-inch cubes. The composition of the stones was determined by chemical analysis: their specific gravities were taken; their weights, after having been dried by exposure to heated air for several days; then their weights after having been immersed in water for several days, so as to become saturated; the object being to ascertain the absorbent powers of the stones, which was further tested by placing them in water under the receiver of an air-pump, and then exhausting the air. The stones were also subjected to Brard's process of disintegration for determining how far a stone will resist the action of frost. Lastly, the cohesive strength of each specimen, or its resistance to pressure, was tested by the weight required to crush it. This weight was applied by means of the hydrostatic press, the pump of which was 1 inch in diameter: 1 lb. at the end of the pump-lever produced a pressure on the surface of the cube equal to 2·53 cwt., or to 71·06 lbs. on the square inch. The weight on the lever was successively increased by a single pound, and, in order to ensure a gradual action, a minute was allowed to elapse previous to the application of each additional weight. The pressure at which the stone began to crack was noted for each specimen, and also the pressure at which it was crushed.

The results of all these experiments, which are stated for each stone,[2] gave a decided preference to the Bolsover magnesian limestone, which is stated to be remarkable for its peculiarly beautiful crystalline structure, while it is the heaviest and strongest of all the specimens, and absorbed least water. Its composition is 50 per cent. of carbonate of lime, and 40 of carbonate of magnesia; the remaining 10 parts consisting chiefly of silica and alumina.

Professor Daniell remarks, that "if the stones be divided into classes, according to their chemical composition, it will be found in all stones of the same class there exists generally a close relation between their various physical qualities:—thus, it will be observed that the specimen which has the greatest specific gravity possesses the greatest cohesive strength, absorbs the least quantity of water, and disintegrates the least by the process which imitates the effects of the weather. A comparison of all the experiments shows this to be the general rule, though it is liable to individual exceptions. But this will not enable us to compare stones of different classes together. The sandstones absorb the least water, but they disintegrate more than the magnesian limestones, which, considering their compactness, absorb a great quantity. The heaviest and most cohesive of the sandstones are the Craigleith and the Park Spring. Amongst the magnesian limestones, that from Bolsover is the heaviest, strongest, and absorbs the least water. Among the oolites, the Ketton Rag is greatly distinguished from all the rest by its great cohesive strength and high specific gravity.

		Silica	Carbonate of lime	—— magnesia	Iron alumina	Water and loss	Bitumen	Specific gravities. Of dry masses	Specific gravities. Of particles	Cohesive powers.
LIMESTONES.	Ham-hill.	4·7	79·3	5·2	8·3	2·5	a trace	2260	2695	57
	Chilmark.	10·4	79·0	3·7	2·0	4·2	a trace	2481	2621	101
	Barnack.	0·0	93·4	3·8	1·3	1·5	a trace	2090	2627	25
OOLITES.	Ketton.	0·0	92·17	4·10	0·90	2·83	a trace	2045	2706	36
	Portland.	1·20	95·16	1·20	0·50	1·94	a trace	2145	2702	30
	Bath Box.	0·0	94·52	2·50	1·20	1·78	a trace	1839	2675	21
	Ancaster.	0·0	93·59	2·90	0·80	2·71	a trace	2182	2687	33
MAGNESIAN LIMESTONES.	Park Nook.	0·0	55·7	41·6	0·4	2·3	0·0	2138	2847	61
	Roach Abbey.	0·8	57·5	39·4	0·7	1·6	0·0	2134	2840	55
	Huddlestone.	2·53	54·19	41·37	0·30	1·61	0·0	2147	2867	61
	Bolsover.	3·6	51·1	40·2	1·8	3·3	0·0	2316	2833	117
SANDSTONES.	Mansfield, or C. Lindley's Red.	[illegible]9·4	26·5	16·1	3·2	4·8	0·0	2338	2756	72
	Kenton.	93·1	2·0	0·0	4·4	0·5	0·0	2247	2625	70
	Heddon.	95·1	0·8	0·0	2·3	1·8	0·0	2229	2643	56
	Darley Dale. (Stancliffe.)	96·40	0·36	0·0	1·30	1·94	0·0	2628	2993	100
	Craigleith.	98·3	1·1	0·0	0·6	0·0	0·0	2232	2644	111

The above table gives the results of the chemical analysis of 16 specimens of stone arranged according

(1) Bolsover is a small market town in Derbyshire, on the borders of the county of Nottingham, and about 145 miles from London.

(2) The Commissioners also state for each quarry its name and situation; the names and addresses of the freeholder, of his agent, and of the quarryman; the name of the stone; its composition, colour, weight per cubic foot; entire depth of workable stone; description of the beds; size of blocks that can be procured; prices per cubic foot of block-stone at the quarry; description and cost of carriage to London; cost per cubic foot of the stone delivered in London; cost per foot of surface of plain rubbed work, as compared with Portland stone; and lastly, where known or reported to have been employed in building.

to their respective classes. The names of the quarries are inserted under the general divisions of the different species of stone, and the specimens were considered as fair average samples of the workable stone in such quarries.

Brard's process for imitating the disintegrating effects of the weather is a valuable test for stone. When water is converted into ice an increase of bulk takes place, and the expansion exerts an irresistible force. If a cavity were left in one of the stones of a building, and this from some cause were to become filled with water, its expansion in freezing would produce on the stone the effects of gunpowder, rending and destroying it; the effects would not be evident so soon as in the case of gunpowder; for the mischief occasioned to our buildings, our water-pipes, ewers, bottles, &c., by freezing water does not in general become evident until a thaw melts the ice, and allows the water to escape. The usual action of frost upon stone buildings is at the surface, where moisture being absorbed, freezes into innumerable small wedges, which, in expanding, destroy the cohesion of the materials of the stone; and at the first thaw a layer is thus removed, and a fresh surface exposed to the weather. The effects are most disastrous among mouldings and ornaments, which afford cavities and sheltered surfaces for the accumulation of wet.

Now the power which stones have of resisting frost, must very much depend on their absorptive power. Stones of similar composition, and even from the same quarry, are acted on very differently by frost; for while one stone soon displays the effects of its action, another may remain uninjured for centuries. By saturating stones with water and exposing them to the action of cold as produced by freezing mixtures, valuable results may be obtained. Such a plan, however, is difficult and tedious, and M. Brard was led to consider whether the expansive force of some soluble salt in crystallizing might not be made to imitate the action of water. After many trials he found that sulphate of soda (Glauber's salts) very closely resembled in its action on stone the freezing of water. In order therefore to determine whether a stone which it was proposed to use in building would or would not resist the action of frost, the following method was adopted:—A saturated solution of sulphate of soda was made in cold water, the stone was immersed, and the solution boiled for half-an-hour; the stone was then taken out and put into a plate with a little of the solution. It was then left in a cool place, and in 24 hours the stone was covered with a snowy efflorescence, the liquid having disappeared either by evaporation or by absorption. The stone was then sprinkled gently with cold water until all the saline particles had disappeared from the surface. After this first washing, the surfaces of the stone were covered with detached grains, scales, and angular fragments, and the stone being one that was easily attacked by frost, the splitting of the surfaces was very decided. The experiment however was not yet complete; the efflorescence was allowed to form, and the washing was repeated many times during 5 or 6 days, at the end of which time, the bad qualities of the stone had become fully established. The stone was lastly washed in pure water; all the detached parts were collected, and by these the ultimate action of the frost upon the stone was estimated.

The effect of this process in various non-resistant stones was remarkable. Some were found to have deteriorated in the course of the third day; others to have entirely fallen to pieces; those of which the power of resistance was somewhat greater, held out until the fifth or sixth day. Few stones, however, except the hard granites, compact limestones, and white marbles, withstood the trial during 30 consecutive days. For all practical purposes, however, 8 days are sufficient to test the resistant qualities of any building stone.

The action of this process is as follows:—the boiling solution dilates the stone and sinks into it to a certain depth, nearly in the same way that rain-water, by long-continued action, introduces itself into stones exposed to the severity of our climate. Water, when frozen, occupies a greater bulk than when fluid, and the pores of the stone not being able to accommodate the increased bulk of water, great pressure is exerted among them, whereby a portion of the water is expelled to the surface, and thus particles of the stone are torn away. So in the saline solution: it is introduced into the stone in a fluid state, and passing into the solid form by crystallization, it occupies a greater bulk, and a portion of it appears on the surface. The repeated washings enable the salt to exert its full amount of destructive action on the stone. Thus the effect of congealed water and that of the efflorescence of salts in the disintegration of non-resistant stones is very similar: water exerts its destructive action on the stones only in a state of snowy efflorescence, which proceeds from below the surface to the exterior, as in the saline efflorescence; while water at the surface of the stones may freeze into hard ice without injury, and salts may crystallize upon them with impunity.

Brard's method may also be applied for ascertaining the solidity and resistant power of bricks, tiles, slates, and mortar. For example, during the winter season M. Vicat composed 75 varieties of mortar with various proportions of sand, and different methods of slaking the lime. [See MORTARS AND CEMENTS.] In the following June these mortars were submitted to Brard's process. Many of them were attacked in 24 hours: almost all of them in 48 hours, and all, except 2, in three days. It was found that a mortar made 10 years previously of 100 parts lime, which had been left exposed to the air under cover during a whole year, and then mixed up into a paste with 50 parts of common sand, withstood the trial admirably during 17 days, while the best stones of the neighbourhood speedily gave way. In this case the solution was saturated *while hot*, and so powerful were its effects that stones, which had resisted the action of frost for centuries, soon gave way when exposed to it. Vicat calculated, that the effect of the saline solution on a non-resistant stone, after the second day of trial, was

equal to a force somewhat greater than that exerted by a temperature of 21° Fahr., on a stone saturated with water.

The action of the process upon bricks proved, that whatever their qualities might be in other respects, if imperfectly burnt they are quickly acted on. The sharp edges of the brick, and then the angles, are first rounded, and then the brick is reduced to powder. Such is the action of frequent frosts on brick. Well-baked bricks, on the contrary, retain their colour, form, and solidity, under the test as well as by exposure to frost. Ancient Roman bricks, tiles, and mortar, and hard well-baked pottery, resisted the process perfectly; as did also the finest white statuary marble, while common white marble was speedily attacked. Portions of some of the buildings of Paris which had been exposed to the weather during 20 years without injury were tested by Brard's process, and were unaffected by it. A large number of experiments were made on stones from the different quarries of France: the action of the salt was continued for 7 days, and the results were recorded: it was then continued for 14 days, and the results compared with the preceding ones, when it was found that the stones marked as good in the first set of experiments retained their character, while the bad stones continued to deteriorate rapidly. By this process the different qualities of stones from the upper and lower beds of the same quarry are easily determined; the stone from the upper bed being often non-resistant and that from the lower resistant, while to the eye both kinds of stone appeared to be identical.

One great advantage of this process is the power which it gives to the architect of selecting a hard durable stone for those parts of a building which are most exposed to the action of the weather, such as the cornice, the columns and their capitals, which are more exposed to the destructive action of rain, hail, and damp air, than the flat surface of a wall.

A Commission appointed by the Royal Academy of Sciences for inquiring into the value of Brard's process, published a set of directions for carrying it out for the benefit of architects, builders, master masons, landed proprietors, and others. These directions may be of value to some of our readers.

1. The specimens of stone are to be selected from those parts of the quarry where, from certain observed differences in the colour, grain, and general appearance of the stone, its quality is doubtful.

2. The specimens are to be cut into 2-inch cubes with sharp edges.

3. Each cube is to be marked or numbered with Indian ink or scratched with a steel point; and corresponding with such mark a written entry is to be made of the situation of the quarry, the exact spot whence the stone was extracted, and other details relating to the specimen.

4. Sulphate of soda is to be added to rain or distilled water until a saturated solution is obtained, which is known by a portion of the salt remaining at the bottom of the vessel after an hour or two, during which the solution must be repeatedly stirred.

5. Put the solution in an earthen pipkin over the fire: when it boils put in the specimens one at a time, and let them all be covered by the solution.

6. Continue the boiling for 30 minutes.

7. Take out the cubes one at a time, and hang them up by threads, so that they touch nothing. Place under each specimen a cup or gallipot with a little of the solution in which the stones were boiled after having strained it clear.

8. If the weather be not very damp or cold, the surfaces of each stone will in the course of 24 hours become covered with small white needles of the salt. Plunge each stone into the vessel beneath, so as to wash off the crystals: repeat this operation 2 or 3 times a-day.

9. If the stone be one that is capable of resisting the action of frost, the crystals will abstract nothing from the stone. If the stone be non-resistant the salt will chip off particles of the stone which will be found in the cup below; the cube will soon lose its sharp edges and angles, and by about the fifth day from the first appearances of the salt, the experiment may be considered at an end. As soon as the salt begins to appear at the surface its deposition may be promoted by dipping the stone into the solution 5 or 6 times a-day.

10. In order to compare the resisting powers of two stones which are acted on by the solution in different degrees, collect all the fragments detached from the faces of the cube, dry them and weigh them, and the greatest weight will indicate the stone of inferior resistance to frost. Thus, if a cube of 24 inches of surface lose 180 grains, and another similar cube only 90 grains, the latter is evidently better adapted to building purposes than the former.

STONE, ARTIFICIAL. Several of the cements described under MORTARS AND CEMENTS may be regarded as artificial stones, and are in fact used as such. The important distinctions between plasters and cements were pointed out in that article. The cements, whether hydraulic or not, readily part with their carbonic acid and water on the application of heat, and become reduced to lime, when, by a peculiar treatment and admixture generally with silicate of alumina, a material is produced which rapidly absorbs the water required for its solidification, and it hardens into a cement or artificial stone. There are many such cements of which the basis is *carbonate of lime*. Plasters, on the other hand, have for their basis gypsum, or *sulphate of lime*, which, on being burnt, parts with its water of solidification without being decomposed. The addition of water to the ground powder, as in the case of plaster of Paris, reproduces the solid form; but by the addition of certain salts of alumina, borax, and potash, the hardness and compactness of the newly-formed stone are greatly increased, and its absorbing power modified. The patented plasters, known as *Parian*, *Keene's*, *Martin's*, and other *cements*, are formed of such materials in certain proportions, as stated under MORTARS AND CEMENTS, where the method of forming *scagliola* is also noticed.

A method of forming artificial stone, different in

principle from that on which plasters and cements are made, has been introduced by Messrs. Ransome and Parsons of Ipswich. "This material is a compound, consisting of grains of sand, pebbles, portions of limestone, marble or granite, clay, or, indeed, any other material, cemented together by a true glass, obtained by dissolving flint in caustic alkali in a boiler at a high temperature, mixing up the materials with this solution into a paste of the consistence of putty, moulding this paste into any required form, and after slow air-drying, burning the articles thus manufactured in a kiln at a bright red heat maintained for some time. In the course of this process the alkali combines with the free silica, and forms a kind of glass, so that the materials become cemented together by a substance which does not admit of the smallest absorption of moisture, and is consequently absolutely unattackable by the frost. It also resists every other kind of atmospheric action, and is extremely hard. It possesses, besides, the great advantage of not contracting sensibly during the last process of baking."[1] This stone is, however, subject to one great disadvantage, viz. some of the salts of soda contained in it are liable to effloresce, and thus greatly to disfigure the work. In preparing the solution of silicate of soda, large rough flints from the chalk pit are used. They are suspended in wire baskets in a high-pressure boiler, the pressure being from 60 lbs. to 100 lbs. on the square inch. For about a ton or a ton and a half of flints, about a quarter of a ton of caustic soda is required (about 56 per cent. of alkali). The fluid silicate of soda is drawn off every 48 or 56 hours, the quantity being about 200 gallons: it is then evaporated down to a sp. gr. of 1·165, when it is fit for use.[2]

With the materials above indicated are manufactured various kinds of stone for garden work, for paving, and a porous substance for filter stones: the latter may be made of any required size; they are cheap, and very effective: they may be cleaned with ease, and be so contrived as to be applied without a reservoir to filter water delivered to houses by the system of constant supply.[3] Scythe stones and grinding stones of various kinds are produced by this method, sand, in certain proportions, forming the base: such stones wear with remarkable uniformity. By employing finer descriptions of sand, clays, &c., all kinds of ornaments are made, such as columns, capitals, balustrades, mouldings, cornices, chimney-pieces, &c.; also floorings, steps, and pavements of every design; and by using various metallic preparations any desired colour may be imparted to them.

Orsi's *brown metallic lava* is composed of broken gravel or stone 3 parts, pounded chalk 2 parts, tar 1 part, and wax $\frac{1}{10}$th part. The tar is first melted in a caldron, and the other ingredients, together with a mineral colour, are added. The artificial stone thus formed is cast in moulds, either into solid blocks, or into hollow vessels for troughs and tanks. Pipes are formed by wrapping a core of wood in paper, and rolling it over a flat table covered with the lava in a fluid state; when a good coating is thus taken up, 3 or more iron ribs are attached lengthways at equal distances by winding wire round them: a second coating is then rolled on so as to cover the ribs and the wire. When cold, the wooden core is withdrawn. For ornamental bricks, tiles, and quarries, an *ornamental metallic lava* is composed of ground flint 2 parts, marble broken small 3 parts, resin 1 part, wax $\frac{1}{10}$th part, colouring matter $\frac{2}{10}$ths part, (such as cobalt for blue, yellow ochre for sandstone, red ochre for red granite, &c.) Ornamental tiles of various colours may be manufactured by casting in this lava, in suitable moulds, pieces of various colours. Suppose a tile were to be formed of a blue, yellow, red, and grey pattern, a blue piece is first cast, and allowed to cool: it is then placed in the centre of the mould from which the yellow piece is to be cast; yellow lava is then poured in round the blue piece, and when the two colours are united they are transferred to the mould for the red pattern; the red lava is then poured in round the blue and the yellow: the three colours are next placed in a fourth mould, and the outside piece of grey is added. All these pieces are cast on a flat-iron, with those surfaces undermost which are intended to form the top surface of the tile, and, for the sake of economy, the coloured portions are not more than from ½ to 1 inch in thickness, a backing of brown lava being added to give the required thickness and strength. When the tile has become set and cold, it is ground and polished by a flat stone with sand and water.

STONEWARE. See POTTERY AND PORCELAIN.

STOP. See ORGAN.

STORAX, a balsamic substance exuding from incisions made through the bark of a small tree, *Styrax officinalis*, growing in the Levant, Palestine, Syria, and Greece. The storax of commerce includes numerous substances of variable character and composition, mostly artificial. Real storax is rare: it occurs in compact masses, fragrant, and of a rich brown colour, interspersed with white tears, hence called *amygdaloid storax*. It was formerly imported, wrapped up in a monocotyledonous leaf, under the name of *cane* or *reed styrax* (*Styrax calamita*). In the drug market two substances, named storax, are met with. One, called *Styrax liquidus*, is usually of a black, brown or grey colour, and of a disagreeable odour: the other, called *Styrax calamita*, is black, brown, or purplish; pulverulent or granular, or in agglutinated lumps. It is said to consist often of pulverized rotten wood imbued with liquid storax; or fine sawdust impregnated with a substance resembling coal tar.

Liquid storax, on being distilled, yields an oil con-

(1) Jury Report, Class XXVII.

(2) It is proposed to apply this solution to wood-work, and other similar materials, and to precipitate the silica in the pores by afterwards laying on a weak acid. Articles may thus be rendered fireproof and indestructible. This application of soluble glass is, however, a very old one: it was used in some of the German theatres many years ago.

(3) The cost of such a filter, passing 300 gallons per day, is 2*l.* 10*s.* Small filters are prepared for the use of travellers at the cost of 5*s.* each. Permanent ascending filters are also prepared with the same material

sisting of 2 atoms carbon, with 1 of hydrogen. It is named *styrole*, and is convertible by heat into *metastyrole*, a solid, transparent, glassy, fusible substance, and having the same high refractive power as the original styrole, to which it may be restored by distillation at a high temperature. Styrole is so volatile that the oily spots made by it on paper disappear at common temperatures in a few seconds. Its sp. gr. is 0·924: it boils at about 293°, and its formula is said to be $C_{16}H_8$, and is isomeric with benzoine.

STOVE—See WARMING AND VENTILATION.

STRASS—See GLASS, Section IV.

STRAW-PLAT—See HAT.

STRENGTH OF MATERIALS. The fitness of different solids to different mechanical uses, their different kinds of strength and stiffness, and the forms and dimensions required in them to answer their ends without danger and without waste, all depend on the forces inherent in their particles, by which those particles act on each other and maintain their connexion. All bodies are known by many proofs to be composed of particles at distances asunder, which, although far below any means of artificial measurement, are very considerable compared with the bulks of the particles themselves, if they have any bulk, for we have no proof that they are not absolutely mathematical points. These particles, whether solids or points, are kept at particular distances apart by the equilibrium between the sum of all the forces tending to bring them nearer, and another force tending to separate them, and which we therefore call *repulsion*. The forces tending to bring them together may be inherent in themselves, or external to them, and transmitted from any distance by this same repulsion among all the surrounding particles. In the simplest known form of matter, viz. gas or air, they are wholly thus transmitted from a distance. In a confined portion of gas or vapour, the only force apparently inherent in the particles, is that of repelling their neighbours. We say their *neighbours*, because the phenomena are incompatible with such a repulsion between any particles, however near, that are not *next* to each other. This repulsion is the only force discoverable in a gas so confined, and must be balanced by the resistance of the confining vessel. But in the open atmosphere, we find it is balanced by a second force inherent in the particles, but too small to be perceptible except in great quantities together, viz. their attraction or gravitation to the earth. The existence of masses wholly gaseous, as comets, shows also that gas gravitates to gas; and we conclude that its particles (like all others that we call matter) *attract* at all measurable distances, from the breadth of the solar system down to that of a hair, although, at the greatest distances to which we can let adjacent ones recede, they *repel*. There must evidently be a distance then, less than a hair's breadth, at which they pass from the domain of one law into that of the other, and neither attract nor repel; and this must be their natural distance, horizontally, at the top of the atmosphere. We say *horizontally*, because vertically they must be nearer, namely, near enough to repel the next layer below, with a repulsion equalling their gravitation to the whole mass of the air and earth. Thus every fluid must, at its surface, be denser in a vertical direction than horizontally, but the horizontal distance of the surface particles must always be the same in the same gas, whatever be the depth of the atmosphere below, and whether attached to the largest or the smallest planet, or to none. Anywhere below the surface they are of course near enough to repel their neighbours all round, and nearer the deeper below the surface; and although the air here at the bottom has been rarefied by pumps above 1,000 times, that is, its particles have been allowed room to recede to more than 10 times their natural distance, this is not far enough to lose their repulsion or rest together as at the top of the atmosphere. We know not how many times their surface distance may exceed this, and yet that maximum distance, we conclude, cannot be a hair's breadth; because the lightest bodies which we can handle, when delicately suspended or floating, gravitate to each other, and although enveloped in films of this repellent air, as can be proved by their refusing to be touched by other fluids in which they are immersed, yet they approach and attract till they are nearer than a hair-breadth, or in what we commonly call *contact*.

The next simplest form of matter to the aëriform is the liquid. In this, also, the particles at the surface, if subject to no external pressure from gas, are at a neutral distance, where they neither attract nor repel, but within which they repel, and beyond which they attract. Yet this distance is many times less than that at which they would behave in the same way as gases. The air we breathe, which we have seen has its particles, we know not how many more than 10 times, nearer than their first neutral distance, has certainly had them brought, by artificial pressure, 4 times nearer than this; and so far was the repulsion from diminishing, that it seemed increased as much as the density, or 64 times. But most other gases, before being compressed to this extent, have some particles brought nearer than the distance at which their repulsion is greatest, nearer even than that at which it has again diminished to nothing, and changed into a new *attraction*, so that they are brought by this second attraction, through the whole range of its action, to the distance at which it changes into a second repulsion, and this is the distance at which they would rest as a liquid in vacuo. But in these cases the external pressure brings them a little nearer still, to where this new repulsion is enough to balance it, or to equal the repulsion of the other particles that remain as gas. So also, in the open air, no particles, whether of gas, liquid or solid, are exactly at a neutral distance, but within a repellent one, and just so far within it that their repulsions (measured in lbs. per square inch) are all equal; although some, such as air, are in their *first* repulsive distance, and others (such as water) in their *second*. If the particles of water be removed to just 12 times their ordinary distance (and have the temperature necessary to keep them there), they will repel almost exactly as

much by gaseous repulsion as they do in the ordinary state by liquid repulsion; that is, they again balance the atmospheric pressure. This difference is not so great as 12 to 1 in any other known liquid and its vapour. In all that have been tried it is less than 8 to 1, in none much less than 6 to 1. But we must not suppose that these at all approach the ratios between the two neutral distances, or those at which the particles rest at the surface of an unpressed liquid and an unpressed gas of the same matter. The difference of these cannot be known unless we had examined matter in the latter state; but it would certainly be much greater than between the same liquid and gas when equally *repellent*, however small that equal repulsion be, or, in other words, however small the equal pressures under which we compare them. It was shown (see STEAM) that the less the pressure common to any water and its vapour, the greater is the difference of their densities; and that Gay Lussac found this difference, under a very small pressure, as 600,000 to 1, or the distance of particles almost as 85 to 1. The reason is, that any change of pressure makes an immensely greater difference in an air than in a liquid. In other words, the same repulsion is elicited by a vastly less approach within their respective neutral distances, of the liquid particles, than of the gaseous ones. When at their second resting distance then (or that at the surface of an unpressed liquid) any disturbance therefrom brings into play vastly stronger attractions and repulsions, than a like or proportionate disturbance from their first or gaseous resting distance would. We say stronger *attractions* as well as repulsions, because although we cannot measure the former, it can be proved that *at the limit* the disturbance of a thing either way, by equal forces, must be equal; which means that the *less* the disturbances each way, the more *nearly equal* do they become, and that they may be so little as to be more nearly equal than any proposed ratio. Thus although a piece of Indian-rubber may be stretched, perhaps, two inches by the same force that would be needed to compress it only 1 inch, any less force would produce a stretching and a compression more equal than as 2 to 1, and by comparing changes small enough, we shall presently find them sensibly proportional to the forces producing them; which is what Dr. Hooke expressed by his famous law, *ut tensio sic vis*, and which applies to all the following matters. So, again, although a removal of all pressure allows air to expand, we know not how many more than 1,000 times, while a doubling the pressure only reduces it 1-half; yet, if, instead of 15 lbs. per inch added and taken away, we compared the effects of 1 oz. per inch, we should find them sensibly equal, and sensibly half those produced by 2 oz. per inch. But even these would have more effect on air than the greatest forces which we can apply have on liquids. The removal of all pressure only causes water to expand as 22,000 to 22,001, or its particles to recede $\frac{1}{66000}$ further apart. So small a change, either way, from their neutral distance must excite forces sensibly equal, for it can be measured that 10 or even 50 times this compression elicits sensibly just 10 or 50 times the repulsion. By the common pressure, the particles at a watery surface are brought $\frac{1}{66000}$ nearer than in vacuo, and as near as at 33 feet below the surface in vacuo. At 33 feet deep in the sea they are nearer by another 66,000th, and so on.

The water in a hanging drop must be rarer than at an ordinary surface; but it would take a drop or thread 33 feet long to pull the particles at its root as much as they are pressed together by the air, or allow them to attain their neutral distance. Of course, they are never beyond this, or *attrahent*, except in a drop hanging in vacuo. As 33 feet to the depth of such a drop, so is $\frac{1}{66000}$ to the fraction of their natural distance that the particles are pulled further asunder by it. Hence the *extensibility* of water (lineally, or in *length*) may be about a 100,000,000th; that is, it may be stretched so much without breaking.

We see then that a removal of the particles of water $\frac{1}{66000}$ nearer or further apart, brings into play attractions or repulsions that, between *two* particles only, are as great as the gravitation between the whole earth and a line of such particles extending 33 feet; which may give us some idea how enormously the first attraction of all particles (or gravity), and the first repulsion (or that causing gaseous elasticity), are surpassed in energy by the forces that keep the particles of liquids, and far more of solids, in equilibrium at their natural distances. It shows, too, that although external forces must be keeping them mostly at a little more or less than these distances, (viz. the atmospheric pressure, keeping nearly all at *repellent* distances, but pulls of all kinds keeping a few at *attrahent* ones,) these effects are all so very minute, that we may regard the actual distances of all particles (not gaseous) as being one of their *neutral* distances, within which they repel, and beyond it attract.

That there are *several* of these alternations from attraction to repulsion, in bodies nearer than a hair's-breadth, may be easily shown with two very plane pieces of plate-glass. First, by floating them on mercury, their own *gravitation* will bring them into what we call contact, such as to cause them to strike with a sound. Yet, even the gravitation of one to the whole earth (instead of to the other pieee) does not always bring them near enough to rub with sensible friction; for one may be laid on the other, and, although ⅛th of an inch thick, will float over it, upheld by a *repulsion* equal to its own weight of more than 2 drachms per square inch; and the effect is too lasting to be due to air unable to escape in time. Now wind a thread of the silk-worm over one piece, so that no part of the thread may cross another; and when the other piece is brought by slight pressure as near as the thickness of this thread, (perhaps rather nearer by its compression,) they will *attract* enough to keep a thick lower plate suspended. Lay them down, and without the silk this same pressure will bring them nearer, near enough to be inclined 15° without sliding off, the friction being about ¼th of the pressure, the ordinary friction of glass on

glass. In this state they are not near enough to produce the colours of thin films; or only, with a heavy upper plate, the pale pinks and greens that Newton showed to require 60 to 70 millionths of an inch of air. The upper plate, then, is again upheld by repulsion, and it will be found that all these colours are produced within the range of a *second repulsion*, which increases in energy up to some hundreds of pounds per square inch, the pressure required to produce the final black colour, or make the intermediate film invisible, *i.e.* to bring or keep the glasses within a millionth of an inch. But when the pressure has exceeded, at any point, 1,000 lbs. per inch, we may remove it; they are in a *third attrahent distance*, if suspended, and the parts within this distance are kept together by far more than the atmospheric pressure. The friction, or resistance to lateral movement, is also so great that we may break in trying to *slide*, much more to *pull* them apart; and being in *optical* contact (*i.e.* nearer than a quarter the interval of a wave of light), they might pass for one piece. Not so, however; for without stopping to inquire whether air permeates this invisible fissure, we shall find that water does, as quickly as the fissures of sugar or cotton, and separates them so much further, that although still too near to reflect light, and still attracting, they are easily separated. Now, as no pressure which we can apply to them before presenting the water will prevent its entry, or make them behave to it as one piece, this pressure is plainly resisted by (or brings them within the domain of) a *third repulsion*. Whether the next, or *fourth attraction*, would be that which unites the particles of the same piece, we cannot tell. There must be a pressure that would mend broken glass as well as tallow, or at freezing as well as at a white heat, and the fine plates cast at St. Gobin are said to have sometimes, when left long pressed together, become absolutely inseparable, and been cut and polished as one. Whatever the numbers of these attractions and repulsions, they must be *equal*, because, as the first, extending to all space, is an *attraction*, so the last must be a *repulsion*,—that by which simple solids like glass resist compression, and which there is every reason to suppose insuperable, or increasing without limit as the particles approach.

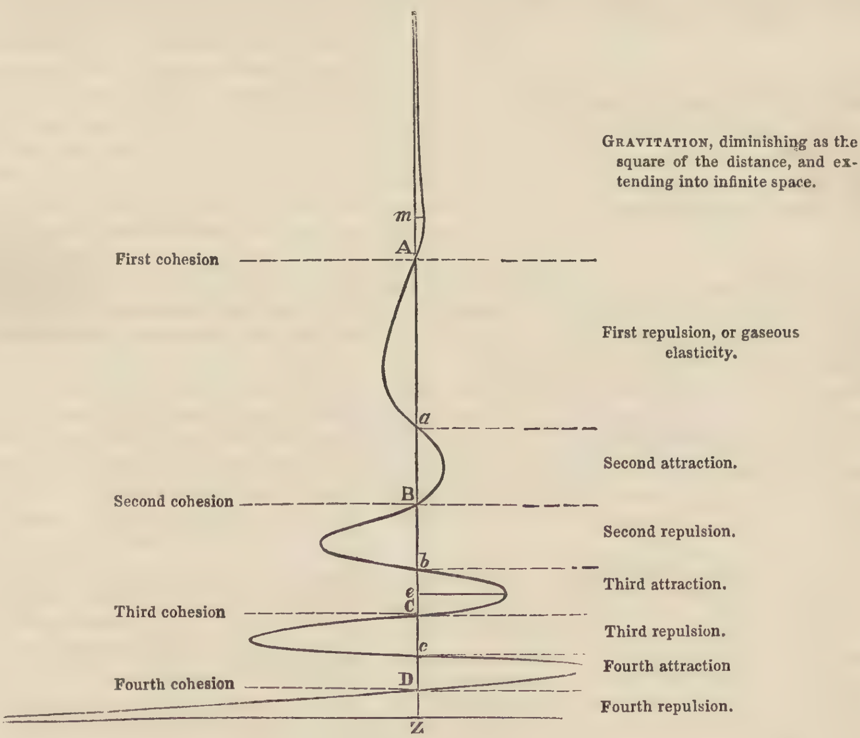


Fig. 2085. CURVE OF MOLECULAR FORCES.

Boscovich, the great investigator of these forces of matter, therefore observed that their whole law must be expressed by some such curve as this, with an unknown number of doublings, whose distance right or left of the line Z*m*, at any point would represent the amount of attraction or repulsion between two particles whose distance is supposed to be measured from Z to that point, on a greatly magnified scale. Thus gravitation, increasing from all distances up to the proximity of Z*m* (where it is a maximum), is expressed by the curve above *m* being a hyperbola, such as perpetually approaches the straight line, but never reaches it. ZA is the distance, less than a hair's-breadth, at which particles cohere, on the top of the atmosphere, where their weight balances their elasticity. All the points A, *a*, B, *b*, C, *c*, D, are neutral

points; but a particle can only rest at such points as A, B, C, and D, because at *a*, *b*, or *c*, the slightest movement gives preponderance to one of the forces that tend to remove it therefrom. It is like the fabled Mahomet's coffin, between the attraction of the earth below and a magnet above; for though there is always a point where their attractions are equal, no body could rest there, as it could between any two *repulsions*, and as a needle does in an electrical helix. The last branch of the curve is shown, like the first, ever approaching and never reaching Z *z*, because the last repulsion must be insuperable; but it is most likely, and consistent with natural analogies, that, as the alternations grow more and more frequent, every force being confined to a far shorter range of distance, as well as far stronger, than the preceding one, their *number* would be infinite, or the curve make closer and closer turns, departing at length beyond any assignable distance from D Z, innumerable times within the distance D Z, or that dividing the particles in an impressed and unstretched solid.[1]

These alternately attractive and repulsive distances may very probably be the same in which the rays of light, passing within a hair's-breadth of the edges of bodies, are known, by the phenomena in their shadows, to be, some attracted and others repelled.

The next simplest form of matter after the liquid, seems to be that of glass, resin, bitumen, and other solids that break with curved polished surfaces, and with equal ease in all directions. If really incapable of crystallizing, we must conclude their particles to have *no polarity*, that is, no sides or corners, and no inequality of these forces in different directions. In all crystals there is such inequality, and the particles are all arranged, by virtue of it, with like parts in like directions, in such perfect regularity, that they can only break with plane surfaces. The simplest break in three or more directions all equally inclined, and the figures when perfect have length, breadth, and height equal, as in the diamond, sea-salt, alum, and fluor-spar. These are the fourth simplest form of matter. The fifth consists of crystals wherein the molecular forces in *one* direction are different from those in all directions perpendicular thereto, but alike in all the latter, and in intermediate directions varying only according to their inclination to this one, called the *axis*, so as to be alike in all that are equally inclined to it. Such are quartz and calcareous spar. Lastly, there are crystals wherein they vary in *all* directions, and the perfect form has length, breadth, and height all different, of which kind are nitre and sulphur.

The seventh simplest kind of matter, and simplest of what may be called composite solids, is the *crystalline*, i.e. a congeries of imperfect crystals adhering in all directions; as marble, and probably all cast metals, although we can rarely see this with the naked eye in any but cast-iron. Here the cohesion of crystal to crystal (which is a very different and far weaker one than that of particle to particle) constitutes the whole practical strength. The multiplicity and confusion of the polarities makes it very equable in all parts and directions, even more so than in the glassy bodies, so that these are *practically* the most *uniform* solids. Probably clay, brick, and most minerals that break with rough or dead faces, are of this class; but being unable, even with microscopes, to examine them near enough to see the glittering of crystalline planes, we call them *granular*, not knowing what the grains may be. Often they are, doubtless, ruins of crystals, worn or rounded in various degrees, even to pebbles or spheres, and then brought by pressure within an attractive distance of each other. But they are probably oftener masses themselves minutely crystalline, or granular, or conglomerated (*i.e.* having a cement between their grains), and their grains again granular, in we know not how many descending orders; just as geological ruins and reconstructions may have produced gravel whose pebbles are of conglomerate, whose nodules are of oolite, whose spherules are of limestone, whose grains are of some crystalline marble and each containing innumerable crystals. The finest sand-grains are really as rugged and complex forms as cliffs or mountains to the naked eye; and such fine-grained and seemingly simple solids as Turkey hone and Tripoli polishing-stone are composed of animal skeletons, a hundred not reaching a lineal inch, that is, a million not filling a cubic inch. But however many the orders of grains in a composite solid, it is only the weakest cohesion, that between the largest grains, which constitutes its practical strength. In a conglomerate, indeed, or cemented sandstone, the cement may, by being stronger than these grains, constitute the whole value of the material, which would then be more useful with the weight of the grains away, and replaced by air or compressed gas, as in bodies that while solidifying have been *leavened* by escaping bubbles. Pumice-stone, a volcanic glassy body minutely leavened, would be of immense utility in architecture, wherever it is common. Many ancient churches, especially the cathedral of Constantinople, were by its means vaulted, in fine and useful modes, not exactly imitable without so strong and light a material.

Differing from the merely granular, there are two opposite forms of composite solid, whose use depends on the first or practical cohesion being different (either greater or less) in one direction than in all others. When *less* in this one direction, the body is *laminar*, as slate or mica; and when *greater* in one direction than the rest, it is *fibrous*, as pumice-stone. These textures are thus the converse of each other; and although producing a tendency to be divided, the one by clefts in a certain direction, and the other in all directions perpendicular to a certain plane, they do not imply the existence of a definite number of plates or fibres. *Minerals*, as the above, are not composed of, but only separable into, plates or fibres, and merely from this polarity (or difference depending on direction) in the *first* cohesion. The *ultimate* or atomic cohesion leads, in crystals, to something

(1) The mathematical reader will readily find very simple equations producing curves answering to this description, so that the whole law, although probably undiscoverable, may be as simply expressible as that one result of it called *gravitation*.

similar, in what are called the directions of cleavage; but of these there are three or four, never an indefinite number as in fibrous bodies, nor a single one as in truly laminar ones; although they nearly approach the latter when one cleavage is very much more decided than the rest, as in mica.

But in *organic* bodies, as wood, hemp, bone, and shell, the fibrousness or lamination is a *structure*, and not simply a property; and the number and size of fibres or plates is definite. The fibres too, which make up the bulk of nearly all organic materials that are used mechanically, are variously and infinitely complex in their own structure; either tubular, or chambered by partitions at long or short intervals, or perforated by many longitudinal canals, and their solid parts built up of a second order of fibres, of ramifying or of spiral vessels, cells, vesicles, &c. Thus the proportion of simple solid to void is rendered vastly less than in the most leavened pumice-stone; and being all arranged with infinite wisdom to yield the utmost advantage of its strength, and not a particle needlessly introduced, the whole edifice becomes often, as in cork, three or four times lighter than potassium, the lightest known simple or compact solid; and incomparably stronger, weight for weight, than any artificial combination of mineral materials can ever possibly be.

As the simplest solids are commonly the hardest, most crystals are intractably so; and hence we use few crystalline bodies mechanically, unless either the adhesion of crystal to crystal is rather weak, as in marble and granite, or the crystals some of the softest, namely, those of carbonate of lime and the seven malleable metals. Malleability consists in a deficiency of the forces that oppose the sliding of particle over particle, compared with the attraction that opposes their separation, or an unusual excess of the latter over the former. Hence, the minutely crystalline mass in which these seven remarkable solids, like most others, cool from fusion, may by *hammering* have all its crystals so flattened out as to approach the texture of a *laminar* solid, or by *rolling* or *wiredrawing* so extended in one direction as to become *fibres;* and it is in this artificially fibrous state that they are most used, because the practical or *first* cohesion (that between the fibres into which the crystals are extended) is increased, at least in one direction, and the *ultimate* cohesion (that which made the crystals hard) is advantageously diminished; for, as no cohesions stronger than the first add anything to the practical strength, but only to the difficulty of working, their strength is an actual disadvantage, unless the material be either shaped in the liquid state (as cast-iron), or used only with such a roughness of finish as shall never necessitate cutting the crystals or grains (as granite and sandstone), or they be so fine as to admit any degree of finish without it (as in clay). Thus, no one would prefer, where they are equally accessible, and have the same practical strength, sandstone, whose grains are harder than any glass, to marble or limestone, whose grains are softer than most iron.

Besides all this, it is remarkable that all the malleable metals, except lead, are by these operations compressed in the directions of pressure without an equivalent extension in any other; that is, while the particles forced further apart return to their former distance by attraction, those brought nearer together by the direct action of the hammer, or the constriction of the wire-drawing hole or rollers, do not all return, but are, some or all, brought into a new attractive distance; so that the number of particles in a given bulk, or the *density* of the metals, is increased, although they have never been enclosed all round, often in iron a *tenth*, or as much as water would be by a pressure of 2200 atmospheres. The former bulk is not regained even by any addition of heat, short of what will fuse, and leave them to a new crystallization; although a much lower heating restores something lost during the compressive treatment, viz. their softness and malleability, which had given place to hardness and brittleness, so that this heating or annealing is necessary from time to time to admit the carrying on of the condensation to any great extent. And as every operation that condenses renders them *hot* (sometimes red-hot) as well as harder and more brittle, and cannot be repeated, nor heat again elicited by any hammering, until they have both disposed of this heat to surrounding bodies and regained their softness and malleability (but not their bulk) in the fire, it is natural to conclude that as much caloric as was forced out by the former condensation must be reabsorbed and fixed in them before another is possible; and yet it does not remove the particles (or only a few of them) beyond their diminished spheres of attraction.

It has by some been thought very unaccountable that the increase of strength gained in these processes should be not in the direction in which the particles are squeezed into a new cohesion, but only in that in which they remain at or beyond their former distance, viz. in the length of the bar, sheet, or wire. But, in fact, the cohesive *force*, i.e. the *attraction*, which resists extension, is *not* even in this direction increased, but, if anything, diminished. The metal is not more difficult to *stretch*, but only to *pull asunder*. It is even *less* elastic to resist or recover from extension, and is stronger only because more extensible; *i.e.* because the attraction, though weaker at any given distance, extends through a greater range of distance, and so acquires a greater force before changing into repulsion. That a body may be broken, some particles must be pulled to the distance where some attraction reaches its maximum. Whatever force can do this, will of course pull them through the remainder of its range, and also through all succeeding attractions, if we suppose them, like the two last (liquid cohesion and gravity), and like all those observed between the glass plates, to have their maxima rapidly less and less as bodies recede. But this need not be supposed to be universally the case; and one effect of forging seems to be the forcing particles asunder in the direction of the length of the body, past the maximum of the attraction that originally confined them, so that they are carried out to

the next attractive range, which happens to be not only more extended than the former, but to have a greater maximum. That a greater maximum may occur exterior to a lesser one, appears from the fact that hardly any solid can, after pulling asunder, be mended by no greater a force pressing the pieces together than that which separated them; although the repulsion which prevents this is exterior to the attraction which has been overcome.

An arrangement of the particles so as to be thus between the limits of different spheres of force in different directions or parts, must be totally incompatible with the formation of a crystal; so that perhaps a liability to such arrangement, arising from there being an unusual number of alternations of attraction and repulsion in a small range of distance, may be the cause of some bodies crystallizing only on the minutest scale and in the most imperfect manner (as malleable metals, wax, &c.), and others not at all, as those which are called *glassy:* consistently with which, the density of glass is found to vary gradually from part to part of the same piece, a phenomenon utterly without parallel in the most coarsely or irregularly *crystalline* masses. Some bodies indeed, as sulphur, can crystallize in two (or perhaps more) incompatible modes, or classes of forms not derivable from each other; doubtless at two different neutral distances of the particles, which will be shown (if it is so) by the two varieties of sulphur, &c. having a definite and constant difference of density.

The existence probably of several slightly different neutral distances, in the case of the metals, seems connected with one very singular property, their causing electric sparks drawn from them to yield light, not composed (like that of the sun or a flame) of waves of all possible lengths within certain limits, but of 6 or 7 definite lengths only, which are all different in each metal, and when an alloy gives the spark, the 13 or 14 due to both metals appear all together.

Solidity consists in that force which we have said is small (compared with the others) in malleable solids, namely, the force that opposes sliding of particle over particle; that is, neither an attraction nor a repulsion, a force acting neither to nor from a particle, but *tangentially* to any circle drawn round it; like the force by which a magnet and an electrical wire move each other. We have no proof, however, that it ever acts as a *moving* force, or brings particles back to or towards a position from which they have been disturbed, as all the attractions and repulsions do. It may, for aught we know, be only a *resistance* to movement, like friction, which, as we saw by the experiments of the glass plates, becomes rapidly stronger at each successive neutral distance. At the *first* support by repulsion it is imperceptible, for one plate slides off the other however level we place it. At the *second* it seems about $\frac{1}{4}$ of the weight or pressure which the repulsion is at any time supporting. At the *third* it is so great that one will not slide off the other in *any* position, nor by a much less force than would overcome their attraction by direct pull. This third friction then exists independently of pressure, or not only in the *repulsive* but at the *neutral* distance; and so in the second, or ordinary friction, it has been proved that the whole resistance may be divided into two parts, one proportional to the pressure, and the other constant however small the pressure, so that this latter would remain were there no pressure or repulsion, *i. e.* at the neutral distance. Now it is a resistant force, like this latter, operating at some of the nearer neutral distances, that distinguishes solids from liquids, or constitutes solidity. In those few bodies, indeed, that are denser in the liquid than the solid state (water, antimony, &c.) there must be a diminution of this force after the particles have approached within its maximum; since the particles of ice have it strongly, while in water, although nearer, they have it not.

No degree of strength in the *radial* forces, or attractions and repulsions, could render a body solid, without tangential force. Indeed the repulsion (and therefore in all probability the attraction too) is greater in water than in many of the most perfect solids. It resists extension probably 50 times more strongly than deal, and more strongly than wrought-iron; and although this resistance or attraction extends through so very small a range (about $\frac{1}{100,000,000}$th of the distance of the particles) that a drop of its own substance hanging less than $\frac{1}{4}$ of an inch suffices to pull it through that range and *break* it, there are many well-known liquids as perfectly fluid as this (treacle is almost so) which show by the threads of them that may hang, an attraction extending through so much longer a range as to equal at its maximum that of many solids strong enough to be used in construction. Perfectly solid brick probably could not suspend so long a column of itself as perfectly fluid glass could; understanding by *perfectly fluid* as mobile or easily disturbed as water. Moderately good brick is pulled asunder by 150 lbs. per square inch, or a column of itself 60 feet deep; and glass as fluid as oil, if not water, can form threads longer than this. Probably a pendant of sandstone (like the "miraculous pillar" in the grotto of Bethlehem) could not hang so far without breaking, as either thoroughly melted glass or the spider-web fluid. This latter, indeed, has been called the "most ductile of *solids*," but is no more a solid than melted glass, which it very closely resembles, and is the only fluid we know at common temperatures approaching it in cohesion.

Still further to show how independent solidity is of cohesive attraction, we may find a converse to the above, in perfect solids whose resistance to extension is not only as weak but as limited as that of treacle, oil, or perhaps water. Such are the crystals of the lead-tree and those in which iodine or sulphur deposit themselves from their vapour, which may fall apart by their own weight while smaller than a globule of mercury that does so. But a perfect solid (as these probably are) can retain any shape whatever, if *small* enough; whereas a perfect fluid can retain no *angular* shape, be it ever so small, no deviation from the sphere, the thread, or other figures of equilibrium, not even so much roughness as constitutes a dulness of polish.

As bodies are more or less solid, then, simply in proportion to the tangential force, independently of the radial ones, we might call the measure of this, their *solidity;* but it is universally spoken of as their *hardness*, although Dr. Young called it *rigidity*, which in common parlance has quite a different meaning. He introduced a useful term, however, to express the mode of measuring it. To overcome this resistance simply, without opposing either attraction or repulsion is, in his language, to *detrude* the solid. Thus joggles in masonry, or treenails in carpentry, driven through two timbers that are in contact, will answer their end as long as they are not detruded, and the rivet of a pair of scissors or pincers can fail only by detrusion. Now detrusion will affect solids in two very different ways, according as the tangential force exceeds or falls short of a certain ratio to the maximum attraction or breaking stretch. Some may be detruded to any extent without ceasing to cohere. Soap is a familiar instance, for, provided we do not *pull* it or any part of it directly asunder, a portion from the middle of a bar may be pushed through between the remaining parts, cohering to them all the while with as much attraction per square inch as at first. We believe that Indian-rubber may be treated in the same way, and so might lead, and probably all decidedly malleable forms of metal. But where this cannot be done, we know no instance of detrusion proceeding to a certain space, like extensibility, and then at the limit producing fracture. Inorganic bodies that may be broken by detrusion (as brick, stone, &c.) seem to be instantly broken by any detrusion however small. As far as we know, then, solids either cannot be detruded without fracture, or can be detruded to any extent without it; and this divides them into two grand classes, those which can be *crushed*, and those which can be *squeezed* or *flattened out*, for both these operations reduce themselves to the detrusion of particles, one with fracture and the other without it. Very composite structures, such as wood, may admit, in certain directions, of flattening to a definite limit, and then crushing, according as the cohesion of different orders of grains or members are called into play; but every uniform solid, glassy, crystallic, crystalline, or granular (with or without subgranulation), even fibrous or laminar (if examined in a definite direction), *i. e.* every mineral body, must belong to one or other of these two classes; although we may be ignorant to which to refer some of the commonest materials from their great strength. Cast-iron and cast-copper and zinc may all be crushed; but brass, the compound of the two latter, it seems, cannot, for a cube of it has been squeezed into half its thickness.

Properly speaking, all that cannot be crushed are *imperfect* solids, so that malleability is the first step of a scale leading to fluidity. Whatever cannot be crushed, can only be broken in one way, by pulling asunder; while *perfect* solids can be broken in two ways, by *tension* or by *detrusion*. It is usual to designate *four* modes of fracture, and four kinds of strength, and also of elasticity, viz. those of *tension*, of *compression*, of *flexure*, (or cross-strain,) and of *torsion;* and doubtless it is useful to have tables of the resistances of given sizes of different solids, and rules for calculating those of other sizes, both to *pulling asunder*, *crushing*, (if capable of it,) *snapping across*, and *twisting off;* as well as to given degrees of disturbance by each of these applications of force; and the amount of disturbance by each that will be restored by their elasticity, or will just begin to cause a new arrangement of particles, or permanent change of form, which is called a *set*. But although this has been done, as we shall show, to some extent, for all four cases, we must impress on the reader that all of them except the tensile trial are only measures of complex effects, very uncertain on account of that complexity; and that all the fractures by pressure, flexure or torsion, are reducible to combinations of the *two* only *simple* cases of fracture, by tension and detrusion, and would be far better calculable if the laws of these two alone had been investigated with a small portion of the labour and expense that has been devoted to these experiments. Thus, when a beam is broken across, whatever be its material, it is first somewhat bent. The particles on the convex side are stretched further apart, and those on the concave side brought closer; until, in most cases, the former pass beyond their attractive distance and separate at the point most stretched, (that is, most curved,) and the fracture is really one by *tension*. In some very incompressible bodies, however, whose repulsion exceeds the tangential or sliding force, as cast-iron, and probably some stones, the failure begins on the concave side by a wedge flying out, to give room for the approach of the parts on each side of it, and thus the fracture is one of *detrusion*. Again, an axle or any similar body is twisted off, if granular, by simple *detrusion* at the smallest or weakest section, the outer grains of course sliding first, and it has been reckoned that the force required is just two-thirds of what would detrude the same cylinder straight across; but if fibrous, it yields by the outer fibres being twisted round the inner, like a rope, and so extended in length till they are pulled apart by simple *tension*. The case of fracture by compression, as in columns, is far the most complex and uncertain effect of the four that have been experimented on. In all columns of the *Doric* proportions, that is, from the smallest length up to six times their diameter, (for the delicate perception of natural effects by the Greek architects, led them to distinguish the limits to this class of columns as exactly as the latest experiments of our engineers have done, or even seem capable of doing,) the fracture is one of *detrusion* along a plane or planes, whose inclination to the line of pressure are always the same in any given material, evidently depending on the ratio between its repulsive and sliding force, just as the inclination down which a body will slide along a plane depends on the ratio between its weight and friction. In Doric columns, this takes place with less force than can bend them, so that poets have been strictly literal in calling them *unbending*. In all longer or slenderer ones, there is a certain force that,

with the ordinary exactness attainable in equalizing the pressure over their ends, may, by approaching one side of the column, run a risk of pressing that side into a concave figure, and making the opposite one bulge. This pressure of course must never be reached. It limits the practical strength of the column, although it may be perhaps greatly exceeded without breaking it, which then happens exactly as in the snapping across of the beam, by either a *tension*-fracture on the convex side, or *detrusion*-fracture on the concave, according to the nature of the material.

The resistances also to a given disturbance of figure by each kind of strain, or what are called the *stiffness* in tension, in flexure, &c., all spring simply from the *elasticity;* which, in its scientific and only exact sense, means precisely the same in solids as in liquids or gases, and applies only to the radial forces, *i.e.* the resistances to extension and compression, and not to the tangential force or resistance to detrusion, for we have no proof of such a thing as any detrusive elasticity, or return of particles once detruded. Such a property has been supposed indeed by some reasoners on the undulatory nature of light, to be required, not in solids, but (what is far more inconceivable) in the rarest and most mobile of *fluids*, that which propagates the waves of light. For as it is proved that the vibrations constituting light are performed in a direction *across* that in which it proceeds, while the analogy of sound led to the gratuitous supposition that the particles of ether moved out of their places to and fro, like those of air, or ears in a cornfield, and acted each upon its neighbour like the successive parts of a *string* along which waves are travelling, and this in every direction alike; this might well lead Sir J. Herschel to say that the so-called *fluid* required to be imagined with properties characteristic of *solids*, or rather to be more solid than *any* solid; and yet, if it could be conceived, would by no means get over the difficulty; for what becomes of the vastly stronger waves that any fluid capable of this, must still more certainly propagate by its common radial elasticity, *i.e.* by compressions and extensions, like the waves of sound, in the *same* direction that the particles are displaced? Now, by the mode in which the writer has always imagined these vibrations, namely, by leaving the particles *in their places*, and supposing them to be merely set *oscillating* or *librating* like the moon, on an axis of their own, and to have any shape but spheres, their repulsions would tend to keep them all in parallel positions, like the atoms of a crystal, or like so many little magnets, and a disturbance of one would be propagated to others all round to infinity, in precisely the way required to account for the vibration always transverse to the progress, and to lead to *every one* of the phenomena of polarization, and the laws of Fresnel's theory, without the least difficulty or deviation from our most common conceptions of fluidity, and without calling into play even the ordinary elasticity of compression, for the *distance* of ethereal particles would be nowhere altered. We mention this because it might be said, that such an inconceivable kind of transverse elasticity as is commonly attributed to this fluid, is likely to be still more a property of solids; whereas we see no reason for supposing it in either one or the other.

The elasticity of solids, then, is simply like that of all matter, the rate at which both the attraction and repulsion (between which the particles rest) *begin to increase*, in their displacement either way from the neutral distance. It is *one* specific quantity for each body in a given state of density, for it cannot be different with regard to compression and to extension, because a natural law cannot be supposed to change *per saltum*, or the Boscovician curve (Fig. 2085) to make an angle just where it crosses the axis at A, B, or C. Its inclination thereto at the point of crossing is the measure of the body's elasticity, at this particular density. That the inclination rapidly alters above or below this, only affects its elasticity in *other* states, rarer or denser, which may vary according to some complex law expressed by the curve; but its elasticity in one given state simply depends on the curve's tangent at one point.

Dr. Young invented the excellent mode of expressing this by the *modulus of elasticity*, that is, the height to which a body would have to be piled in order that any small addition to its top, of its own substance, might compress the rest by a quantity equal to its own bulk. The advantage of this mode is, that we measure the elasticity by only *one* kind of unit, feet, or miles, and one number, the *height*. By any other way we must introduce three arbitrary quantities. Thus we may say that wrought-iron is extended or shortened $\frac{1}{10000}$th of its length by every added tension or pressure of a ton per square inch. This is an instance easily remembered; but no other substance would have the same simplicity of numbers, if measured the same way, and the inch and ton are both arbitrary and artificial. To express this in Dr. Young's way, we find what height of this substance would be compressed the $\frac{1}{10000}$th by an addition as long and broad as itself, and $\frac{1}{10000}$th as high. Now, a column of water 34 feet high presses 15 lbs. per inch, like the atmosphere. To press a ton per inch, it must then be 5,075 feet high; but iron, being $7\frac{1}{2}$ times as heavy, need only be 677 feet. This compresses any iron below it $\frac{1}{10000}$, and therefore, the iron below must, to be compressed 677 feet, be 10,000 times 677, or 6,770,000 feet deep, or 1280 miles, which is its *modulus of elasticity*.

The modulus of elasticity of air, at the common density, will thus be found by considering what height of it would press with a given small pressure, say of 1 lb. per inch, which we know compresses that below it $\frac{1}{15}$, and thus a column of 15 times that height would be compressed the length of the compressing column. The modulus is about $5\frac{1}{3}$ miles, and that of any other gas, at the common pressure, will be more or less, inversely as its density, so that, at equal *densities* their moduli seem to be alike.

It is very strange that the moduli of all *liquids*, even so different as mercury, water, and alcohol,

seem, as far as they are known, *equal*, viz. about 75,000 feet, or 14 miles.[1] This depth of each, or, indeed, the depth of the modulus of any substance, would compress its bottom into twice the density of its top, provided the elasticity remained equal throughout, or at all these densities; but such is certainly not the case with gases, nor probably with any bodies.

The modulus of elasticity is necessary to be known before we can frame trusses of any material so as to retain a desired form exactly, and not to bend in any of their parts. By a *truss* we mean any arrangement of bars to support some weight by their direct or lengthway strengths only; that is, by compression and tension, without any liability to flexure; and this is the only scientifie or really economical mode of combining any fibrous material (alone or with granular ones), to uphold roofs or bridges, and the only mode regarded as legitimate or rational in most modern countries. [See CARPENTRY.] Now, if a truss (as Fig. 2086) were merely drawn, full size, and then

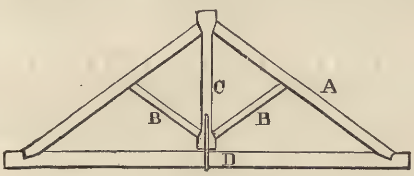


Fig. 2086.

the pieces formed exactly as in the drawing, the erected truss would not have the form of the drawing; for every piece that acts by resisting compression, as A, A, B, and B, would be *shortened* ere the repulsion could be elicited by which it acts; and every piece tying others, or resisting extension, as C and D, would be *stretched* a little ere its particles came to the distance where their attraction yields the requisite resistance. Thus the form would droop towards that of Fig. 2087. To ensure the intended form, each

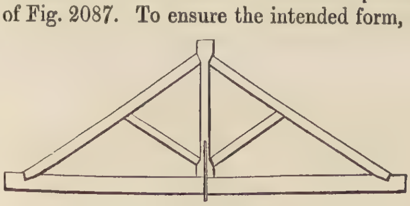


Fig. 2087.

tensile piece or tie must be made originally *shorter*, and each compressed piece or stretcher originally *longer*, than they are intended to become ana are drawn in the design; and to find the differences of the lengths drawn and those made, we must reckon the pounds pressure or tension borne by each, thence how long its own scantling would have to be extended to weigh that number of pounds, and this length will be a second proportional to the modulus of elasticity, the third being the actual designed length of the piece, and the fourth the correction or difference required.

The modulus of elasticity also measures the stiffness of flexure (which is all that we commonly understand by stiffness), and observations of this have been used as the easiest means of determining that modulus. In bending a bow, it is merely the *attractions* of the particles next the convex side, and *repulsions* of those next the concave, that constitute the active or measurable resistance. The hardness or passive resistance to detruding force is indeed necessary to confer the *ability* thus to oppose and recover from bending. Without it the bow would be fluid; but yet it does not, as long as it remains unconquered, at all affect the stiffness, which depends solely on the elasticity common to solids and fluids, that of attraction and repulsion. When, indeed, the body takes any *set*, or does not wholly recover, but permanently keeps a new form, it is this tangential force, or *hardness*, that has yielded somewhere, by allowing a sliding of some particles into new places. It is then as stiff in the new form as the old, and will admit as much deviation therefrom before taking another set. Thus the *elastic flexibility* is measured, not by the extent to which it may be bent, but through which it will *return*, however far bent; and this is a constant measure in any one substance, definable by the number of times a straight bow's thickness is contained in the shortest radius of curvature it may assume at any point, and recover its straightness. So also of simple tension. The *elastic extensibility* is the fraction of its length that it will *return* through, however far extended. Again, the *elastic torsibility* may be defined by the fraction of a cylinder's length, that its diameter will be, when it is just capable of returning *one revolution*, however many times twisted. Lastly, the *elastic compressive limit* (which is not, like the three former, of much use to know) is the fraction of a body's depth that it may be squeezed through, and recover. All these four numbers or fractions are constant for any one solid, whether they are limited by *setting* (as in lead), or by *fracture* (as in stone); and it might be supposed at first that being measures of the same thing in different ways, (viz. the relation between the elasticity and hardness,) they would all be deducible from one another, or bear a constant proportion; but, in fact, they are not measures of the same thing, except perhaps the extensibility and torsibility, and, in one rare case, the flexibility. To understand this, we have only to remember that the modulus of elasticity is not constant for any body, but varies with every change in the distance of the particles, and so does probably the hardness, or tangential resistance. But, of the above four numbers, none depends on the *common* modulus or *common* hardness, those at the *neutral* distance of the particles, but at some strained distance. In the cases of simple tension (when limited by setting) and of torsion, this distance is merely the *greatest* they can be strained to without overcoming the hardness, so that between these we may expect a constant relation. In tension limited by fracture, the hardness is not concerned at all; for the extensibility, when it is a *breaking* extensibility, applies to liquids, we have seen, just as well as to solids, being simply the measure of how far the neutral distance of particles is exceeded by the distance where the next attraction is a maximum, or, in fact,

(1) In all the works which we have seen, this is called 750,000, after a misprint in Dr. Young's original Lectures.

what ratio *e* c, for instance, in the curve, Fig. 2085, bears to c z. In the case of compression, the limit, whether by crushing or flattening, evidently depends on quite another modulus of elasticity and another hardness, those at the *nearest* distance the particles can reach without detrusion. Lastly, in the case of flexure, the limit may be either by setting, by tensile fracture on the convex side, or by detrusion of a wedge from the concave side. Setting, however, as well as fracture, will begin on that side whose particles first reach the limit at which the hardness yields, and allows them to slide. It might be thought, then, that whichever is smallest, the limiting *extensibility* or *compressibility*, the flexibility will be deducible from, and bear a constant relation to, the lesser of them. It would be so if the approximation and separation of the particles most acted on, those in the convex and concave surfaces, were equal; but this can occur only on the supposition that their attraction and repulsion vary exactly as fast and by the same law in proceeding each way from the neutral distance; which amounts to supposing the Boscovician curve to bend opposite ways like an ∫ in leaving its axis, and this with exactly similar curvatures on each side as far as the point reached at the yielding; *i.e.* supposing the modulus of elasticity within these limits (represented by the inclination of any point of the curve) to be a maximum at the neutral distance, and diminish *both* ways therefrom, alike and equally; whereas it is far more likely in all cases to increase one way and diminish the other; that is, the curve to bend the same way before and after crossing the axis. Now, owing to this, that the aggregate of all the attractions in a bent body may balance that of all the repulsions, the numbers of particles attracting and repelling cannot be equal; nor are the forces of the *most* strained ones of each kind *necessarily* so. At the *beginning* of flexure, indeed, both must be equal, because any indefinitely short piece of the Boscovician curve is virtually straight (as of any curve), and so the modulus is then equal for all the particles, and, to effect the balance, there must be an equal number of them attracting and repelling, and the neutral plane (or that in which particles retain their neutral distance) must pass through the centre of gravity of the body's section. Hence the *stiffness* in *flexure* (not the *strength* or *breaking* flexure) bears a fixed relation to the common modulus of elasticity, as long as the flexure is very small. The same relation will extend to any flexure, and even to the limits or breaking *strengths* by tension and flexure, only in the rare or perhaps impossible case above supposed. In all other cases, the different variations of the elasticity in removing particles further, or bringing them nearer, that is, the dissimilarity of Boscovich's curve on each side of the neutral distance c, will cause that the further the bow is bent, the more unequal become the number of the particles compressed and extended, in order that their aggregate attractions and repulsions may be equal; and thus the neutral plane moves away further and further from the centre of the section, till, at fracture, it has a certain definite position, depending on the nature of the solid as well as the form of section. In most woods, formed into a rectangular beam, it is about three-eighths of their depth from the convex side, as may be seen by the appearance of the broken surfaces. In cast-iron, on the contrary, it has been found to move the opposite way until it is 4 times nearer the concave than the convex side.

In bodies whose flexure is limited by fracture on the convex side, this limit will plainly, like that of extensibility, be independent of the hardness, since no detrusion happens. It will depend only on the elasticity common to fluids and solids: but not on any *one* modulus thereof, but on the whole series of them, that is, the whole figure of the Boscovician curve from the attractive maximum *e* which has to be overcome, down to a point about as far on the other side of c. We say *about* as far, not exactly as far, because the repulsion of the particles brought nearest need not equal the attraction of those that yield, for it is the *aggregate* forces of *all* the attracting and all the repelling ones that are equal, not the *greatest* of each.

It must further be remembered, that although the limits above defined, or extreme extensibility, flexibility, &c., are useful data, we cannot from these and the common modulus of elasticity deduce the *strength*, *i. e.* the forces producing those extreme extensions, flexures, &c.; for these depend not on the common modulus, but on the new one, belonging to the particles strained to the utmost; or, in the case of flexure, on *all* the moduli for them in every intermediate state.

Next to the form of that part of the Boscovician curve above described, the most useful determination would be the law by which the sliding resistance or hardness varies with the distance to which the sliding particles are pulled apart or pressed; or, what is equivalent to this, the force that will produce detrusion when acting in all directions inclined to the detruded surface. This might be expressed by a curve like B D F, Fig. 2088, in which A B is the *modu-*

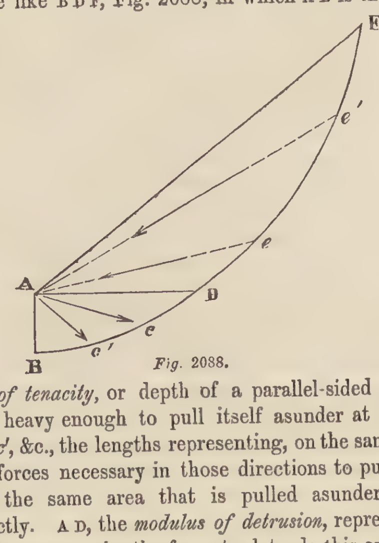


Fig. 2088.

lus of tenacity, or depth of a parallel-sided pendent just heavy enough to pull itself asunder at the top. A *c* A *c'*, &c., the lengths representing, on the same scale, the forces necessary in those directions to pull asunder the same area that is pulled asunder by A B directly. A D, the *modulus of detrusion*, representing, on the same scale, the force to detrude this same area without opposing the elasticity either of attraction or

repulsion. This was thought by Dr. Young, from a few experiments, to be generally about twice A B (as if the curve were a parabola with its focus at A). Dr. Robison also made a few experiments on pins of weak materials passed through holes in three iron bars and detruded, and found the detruding force to exceed the tenacity, in a soft sandstone, as 575 to 205, and in softer bodies to be from *once and a third* to *double* of it. Again, A*e* A*e'*, &c., would be the forces necessary to produce the same effect in these directions, where a portion of them goes to press the solid together and (if the force of hardness be analogous to friction) to increase the resistance to detrusion. F A D, the inclination to any compressing force, at which it will, if strong enough, produce spontaneous detrusion as in the crushing of columns; which angle, according to Hodgkinson's experiments, is 35° in cast-iron. F A, the *modulus of crushing*, or height to which a perpendicular precipice of the substance must be piled in order to crush its own base, which it will do so as to slide off and leave a bank whose inclination to the vertical is F A D. This curve, giving the law of hardness, as Boscovich's does that of elasticity, the two would embody, as far as we know, all the specific mechanical distinctions of one simple solid from another, all the peculiarities of its consistence, and enable all its behaviour under strains to be deduced. The *hardness* curve, however, is not merely

TABLE I.—STRENGTHS INDEPENDENT OF HARDNESS.

Specific Gravity.	Substance.	Modulus of Elasticity.	Modulus of Tenacity.	Weight thereof for 1 sq. inch.	Lineal Breaking Stretch.
		feet.	inch.	grains.	
·0012	Air	28,000	unknown if	any.	...
1·0000	Water	75,000 Y.	0·22	55½ G.L.	·00000006 +
13·6	Mercury	75,000 Y.	0·18	590 G.M.	·00000006 ±
			feet.	lbs.	
1· +	Juice of White Bryony Berries	unrecorded.	2 +	...	13· + Rob.
1·29	Plaster of Paris	unknown.	120	67 Mo.	...
1·6 to 2	Brick, pale red	...	300 ±	280 G.M.	...
2·706	White Marble	2,150,000 T.	464	551 H.	.000717 T.
11·353	Cast Lead	146,000 T.	370	1,827 Re.	unrecorded.
11·3 +	Lead Wire	...	495 ±	2,464 G.M.	...
1·975	Bath Oolite	...	540	478 T.	...
11·407	Milled Sheet Lead	...	670	3,360 T.	...
2·362	Craigleith Sandstone	...	753	772 T.	...
2·113	Portland Oolite	1,672,000 T.	935	857 T.	·000558 T.
7·291	Cast Tin	1,453,000 T.	1,497	4,736 Re.	...
7·3 +	Tin Wire	...	2,120	6,700 Re.	...
7·028	Cast Zinc	4,480,000 T.	1,876 +	5,700 + T.	·000416 +
2·621	Dundee Sandstone	...	2,330	2,661 T.	...
19 238	Cast Gold	...	2,900 +	20,160 G.M.	...
21· +	Platinum Wire	...	4,200	38,000 G.M.	...
7·1 ±	Cast Iron, Scotch and Welsh, 1842	5,750,000 T.	4,300	13,440 H.	...
19·5 +	Gold Wire	...	4,400	31,300 G.M.	...
8·396	Fine Brass (Copper 2, Zinc 1)	2,460,000 T.	4,931	18,000 Re.	·00075 T.
8·788	Cast Copper	...	5,000	19,000 Re.	...
·987	Hempen Rope, not cable-laid	...	5,280	2,400	...
7·113	Cast Iron, cast horizontally, 1816	...	6,043	18,656 Re.	...
7·074	———, cast vertically, 1816	...	6,347	19,448 Re.	...
2·752	Westmoreland Slate	12,900,000 T.	6,140	7,870 T.	·000611 T.
1·66 ±	Ox Bone	...	6,600	4,928 Mo.	...
2·5 ±	Plate Glass	...	7,200	8,960 Mo.	...
2·75	Scotch Slate	15,790,000 T.	7,400	9,600 T.	·0006 T.
11·091	Silver, cast or wrought	...	8,200	38,000 G.M.	...
8·879	Wrought Copper	...	8,769	33,700 Re.	...
2·75	Welsh Slate	13,240,000 T,	9,100	11,500 T.	·00073 T
1·3	Whalebone	1,458,000 T.	10,000 ±	5,600 T.	·0068 T.
				tons.	
7·5 to	Iron Sheet, cut lengthwise	...	9,296	14 Mi.	...
7·7	———, cut crosswise	...	11,950	18 Mi.	...
8·153	Gun-Bronze (Copper 4, Tin 1) hard	2,790,000 T.	11,914	16 Re.	·00104 T.
8·8 +	Copper, Sheet	...	12,400	21 K.	...
8·9 ±	Copper Wire	...	15,000	27⅓ K.	...
7·6	Iron Bar, English	7,750,000 T.	16,600	25 L.	·12 Tl.
to	———, Russian	...	18,000	27 L.	...
7·8	———, best Swedish	...		...	·25
	—— Wires, $\frac{1}{10}$ inch diameter	...	26,560	40 Tl.	...
	Steel, Damascus	...	20,000 ±	31 Mi.	...
	——, do. twice refined	...	29,000 ±	44 Mi.	...
7·8	——, English raw	...	33,000 ±	50 Mi.	...
to	——— shear	...	37,000	57 Re.	...
7·9	——— blistered and hammered	...	39,000	59½ Re.	...
	——— cast	...	29,000	44 Re.	...
	——— cast and tilted	8,530,000 T.	39,800 ±	60 Re.	...
·6 ±	Mahogany, Honduras	6,570,000 T.	30.000 ±	3½ B.	
·75 to ·9 +	Oak, European	4,730,000 T.	30,000 ±	4 to 5 B.	
·65	Pear-tree	...	35,800 ±	4½ B.	
·7	Beech	4,600,000 T.	36,800	5 ± B.	
7·8	Iron Wire, $\frac{1}{20}$ to $\frac{1}{30}$ inch diameter	...	39,840	60 L.	
·9	Teak	...	40,000	7 B.	
·56	Red or Yellow Deal	8,333,000 T.	46,200	5 ± B.	
·9 +	Box	...	51,400	9 ± B.	
·54	Elm	5,680,000 T.	55,000	6 B.	
·5 +	Larch	4,415,000 T.	56,000	6 B.	
·7 ±	Ash	4,970,000 T.	58,500	8 B.	
·5 ±	White Deal	8,970,000 T.	59,000	6 B.	
1·1 +	Paper glued together in strips	...	60,000 ±	13 Mo.	
7·8	Iron Wire, $\frac{1}{30}$ inch diameter, best	...	60,000 ±	90 + L.	
·46	American Pine	8,700,000 T.	63,000	6 B.	
1· +	Hemp Fibres glued together	...	100,000 +	41 Mo.	

AUTHORITIES.—B. Barlow. G.L. Gay Lussac. G.M. Guyton Morveau. H. Hodgkinson. K. Kingston. L. Lamé. Mi. Mitis. Mo. Moseley. Re. Rennie. Ro. Robison. T. Tredgold. Tl. Telford. Y. Young.

definite in form, but also in *size*. We may conceive two bodies as different as jelly and iron with the same form of this curve, but the modulus AB would probably be an inch in some kinds of jelly, and exceeds a mile in all kinds of iron.

The measures called *moduli*, which are definite lengths, heights, &c., of the solid's own substance, and not weights, far more truly express and give us truer ideas of the relative strengths or constructive values of different solids, than the common tabular *weights* do, while they are quite as applicable in calculation. Solids are mechanically valuable in proportion to the boldness of scale and lightness of proportions, that structures of them may receive; that is, to the scale on which they may embody any given form (such as fluids could not embody at all) and retain that form in spite of their own weight. Now this is proportional, not to the common tabular strengths, but to the moduli. Thus the former are greater for metals than for woods, but the moduli are greater for woods than metals, and this latter gives the true relative boldness attainable in these two classes of material,—as a comparison of existing wood and iron bridges, roofs, &c. shows.

Table I. contains some of the most trustworthy measures that have been made of these elements: the chief rules for applying them will afterwards be given.

The bodies are arranged in the order of their real tenacity, *i.e.* the tenacities of equal *weights*, and it will be seen that *hemp* immensely excels in this property all others that have been measured; for we have no measurement of the bamboo stem, nor of hair, and many vegetable fibres that may excel hemp. Next to it come the strongest of three widely differing classes, common woods, pasteboard, and the very best fine iron wire, and these in their most tenacious forms seem equal. Vegetable bodies would be incomparably superior to all mineral ones, but for the singular property of the best steel and iron wire, which seem a sort of artificial organisms by which we can just approach and rival the most tenacious of common woods. If a shaft existed 10 miles deep, no substance in the table but the last four would be available for letting down to the bottom. All the rest would break by their own weight, and were it 12 miles deep, only hemp, of all bodies yet measured, would serve.

The *stiffest* matter yet examined, will be seen, by the modulus of elasticity, to be slate, and the stiffest kind, Scotch slate, a primary rock. Were the earth's interior formed of any other substances yet measured, it may be reckoned that the compression would so condense them towards the centre, as to make the mean density far exceed 5, the greatest that is reconcileable with astronomical phenomena; but the least compressible rocks are evidently placed lowest, and if this Scotch slate extended to the earth's centre, it would not acquire even the density that we know to exist there.

The columns relating to absolute tenacity are of little practical use, (though this is what most experimenters have chiefly observed,) for no material can safely be strained in construction to the point of gaining any *permanent* extension: but the modulus of elasticity enables us to reckon the extension, compression, (in length,) or deflection of any body by a given force, so long as it suffers no *set* or permanent change.

To find the extension or compression lengthwise, the *square* of the body's *length* in feet must be multiplied by the straining force; and then its *weight* (in the same denomination as that force) by the modulus of elasticity; and the former product divided by the latter will give the alteration of length in feet (or decimals of a foot). No dimension but the length need be known.

The compression thus found for pillars, struts, &c., is of course independent of any shortening by *bending*, which (as will presently be seen) cannot, in legitimate construction, be possible by any *lengthway* pressure whatever. The deflexion, however, of long bodies by a *cross-strain* has nearly as much need to be found, in *wooden* construction, as the compressions and extensions by lengthway strains. It has *no application at all* to any other material than *wood*, because no honest constructor would require other materials in lengthy pieces, (into which they must purposely be made,) to bear a pressure on one side opposed only at distant points on the other side; such being the precise kind of form and mode of treatment which we learn, from the earliest experience, to choose for bodies which are intended to be broken, and hence are made not inconveniently strong. Barley-sugar, for example, is made into sticks, and not retailed in blocks or loaves. In speaking of *beams*, however, we use the term as excluding *architraves*. These act differently, and yield their full strength, for there is in cross-strained bodies, as well as pillars, a certain proportion between bearing length and thickness, within (or shorter than) which proportion, they will never break by flexure by any load whatever; but the centre part will fall through and leave the ends behind, sooner than bend sufficiently to break. This proportion will vary with the ratio of the tenacity and hardness to each other, which has been measured in only one instance—Dr. Robison's "soft sandstone," and it gives, we believe, a limiting ratio of bearing length to depth very near the greatest existing in ancient architraves, *i.e.* in the shallowest Corinthian ones, and certainly greater than in any Doric or Egyptian. It is only cross-strained pieces of a longer proportion than this limit, that we call *beams*; those shorter are properly *architraves*, and are true in principle, wasting none of the strength of the material, although perhaps they should be regarded as superseded, (except in stone districts, and on the smallest scale,) by the admission, for these 1,900 or 2,000 years, of arches or oblique-pressure construction into all building.

Wooden beams, then, being the only ones which we need consider, and these being unlikely to be ever used with any shape of section but *rectangular*, the following rules will determine the deflection by a given load. By the *deflection* is understood the greatest space any part is displaced from its un-

loaded position, measured by the usual units—feet or inches. But we must evidently always allow a greater or less deflection as a timber is longer or shorter; so that a certain fraction of the length of the beam must in all cases be the quantity allowed, and it is more useful to get this fraction at once than the absolute measure in inches or parts of inches.

For a bracket-like beam, projecting beyond a fulcrum and loaded at the end, take for a dividend, two-and-a-quarter times the load multiplied by the cube of the projection. For the divisor, multiply together the modulus of elasticity, the weight of the beam's projecting part, and the square of its depth (at the fulcrum). The quotient of the former by the latter, is the fraction of the beam's projection which it will be deflected.

In a *balanced* beam loaded at the ends, each arm independently bends by the above rule.

A *spanning* beam, resting *loosely* on its supports and loaded in the middle, is a balance-beam turned upside down. Therefore take the upward resistance of one support, namely, *half* the middle load, and the above rule will give the fraction of its *half* length that the centre is deflected.

A spanning beam that crosses and is *fixed* to its supports, as when a long timber lays across several supports, will evidently be less deflected than if it were cut through on each support, or even the top fibres only cut and allowed to separate. The deflection of a length of this, between two supports will, it appears to us, be only a *quarter* as great as if it were cut from the adjoining lengths.

All these are deducible from the simple principles of levers, on the supposition of the attraction and repulsions of the particles remaining equal, and the neutral plane in the middle of the depth; which is not perceptibly erroneous, in wood, up to any safe amount of deflection.

It has also been proved that a weight *equally distributed* along a *bracket*-beam produces *three-eighths* the deflection that it would if collected at the end; but on a *spanning*-beam, *five*-eighths of the deflection it would cause if collected in the centre.

All the columns in TABLE II. are practically useful, although the first three, in the case of all bodies without perceptible ductility, (*i.e.* all non-metallic minerals) repeat the numbers of the former table, because these bodies suffer by extension no permanent change till they are pulled asunder. The application of the third column to find the smallest scantlings for ties, king-posts, and other tensile pieces is obvious. The tension they are to suffer, being divided by the weights in this column, gives the area in square inches that would be permanently stretched by that tension. Perhaps *twice* this area may be considered enough to give to *ductile* ties, as wood and wrought metal; but *at least four times* the area must

TABLE II.—STRENGTHS AFFECTED BY HARDNESS.

Specific Gravity.	Substance.	Elastic Extensibility.	Modulus of the same.	Weight of this Modulus for 1 sq. inch.	Elastic Linear Compression.	Modulus of the same.	Weight of this Modulus for 1 sq. inch.
			feet.	lbs.		feet.	lbs.
2·5 ±	Chalk	...	...	...	...	461 ±	500 R.
2·085	Brick, pale red	...	290	275	...	621	564 R.
2·168	——— red	...	...	...	...	858	808 R.
	——— yellow Hammersmith pavers	...	...	...	...	1,064	1,000 R.
	——— do. burnt	...	...	...	...	1,532	1,441 R.
	——— Stourbridge fire-brick	...	...	...	...	1,825	1,716 R.
2·316	Derby Sandstone	...	...	...	...	3,126	3,142 R.
2·428	Do. another quarry	...	...	...	...	4,123	4,344 R.
2·428	Portland Oolite	·000558	935	875 T.	·002	4,000	3,729 R.
2·760	Italian Statuary Marble	·000717	464	551 H.	·007	5,058	6,058 R.
2·452	Craigleith Sandstone, *against* the strata	...	...	...	...	5,156	5,488 R.
2·507	York Magnesian Limestone, *either way*	...	...	...	...	5,251	5,712 R.
2·662	Cornish Granite	...	...	...	...	5,502	6,360 R.
2·506	Bramly Fall Sandstone, Leeds	...	...	...	...	5,571	6,058 R.
2·53	Dundee Sandstone	...	2,330	2,661 T.	...	6,038	6,630 R.
2·452	Craigleith, *with* the strata	...	753	772 T.	...	6,498	6,916 R.
	Devonshire red marble	...	...	...	...	6,623	5,828 R.
	Peterhead Granite	...	...	...	...	7,386	8,280 R.
2·598	Black Limerick Limestone or Marble	...	...	...	...	7,607	8,855 R.
2·697	Black Brabant do.	...	...	...	...	7,876	9,200 R.
2·599	Purbeck shelly do.	...	...	...	...	8,120	9,160 R.
2·726	Italian veined White Marble	...	...	...	...	8,183	9,682 R.
2 625	Aberdeen Grey Granite	...	...	...	...	9,581	10,912 R.
2·871	Red Porphyry	...	...	...	...	28,455	35,568 T.
8·879	Wrought Copper	...	...	...	...	26,737	103,000 R.
8·788	Cast Copper	...	...	...	...	30,689	117,000 R.
7·113	Cast Iron, horizontally cast	...	...	...	...	52,422 R.	93,000 to 176.000 R. and H.
7·074	——— vertically cast	...	...	...	...	58,040 R.	
·7	Beech	·00175	7,500	2,360 B.	...	...	...
·56	Larch	·0019	8,500	2,065 B.	...	21,000	4,920
·76	Ash	·0022	10,500	3,540 B.	...	...	...
·75 to ·9	Oak, English	·0023	11,000	3,960 T.	...	11,100 ±	4,000 R.
·54	Elm	·0024	13,700	3,240 B.	...	5,040	1,200 R.
·56	Mahogany, Honduras	·0024	15,600	3,800 T.	...	...	...
·557	Red or Yellow Fir	·0021	17,500	4,290 T.	...	...	...
·47	White do.	·0021	17,600	3,630 T.	...	7,680	2,000 R.
·46	American Pine	·0024	20,900	3,900 T.	...	...	...

B. Barlow. H. Hodgkinson. R. Rennie. T. Tredgold.

be insisted on when it is not a stretching but a *breaking* area that is thus found, viz. in all the bodies without sensible ductility.

The application of the last column to the sizing of struts, columns, collar-beams and all other pieces acting by lengthway repulsion alone, is equally obvious. The pressure they are to suffer, divided by the weights in that column, gives the area in square inches that would just be either permanently shortened or crushed, and twice this area in the former case, or four times in the latter, may be regarded as the smallest allowable. But this of course disregards all risk of *bending*. Now this, we have seen, can only occur in pillars exceeding a certain proportionate length, which in cast-iron has been found by Professor Hodgkinson to be *six* times the middle thickness (or the Doric proportion), and in substances with a smaller flexibility in relation to their hardness, as stones, would probably be found greater and near the limiting proportion of Corinthian columns, viz. *eleven* times the middle diameter. Accordingly there will be waste whenever lengthway compressed bodies are left unstayed laterally for a greater interval than 10 or 11 times the thickness in the direction of the stays. This was universally attended to in all real architecture, with the exception of a few pillars contrived as feats, between A. D. 1200 and 1250,—for showing how slender they could be made. Afterwards it regulated all the Gothic mullion and transom work, as it had previously done the classic orders. Even now, workmen left to themselves will not transgress this rule in carpentry. A principal rafter is a lengthway compressed member, but for other reasons is best made much more deep than wide. We accordingly stay it laterally by the battens or horizontal rafters, at intervals not exceeding 10 times its *width*, and in the other direction by struts from below, at intervals by no means 10 times its *depth*. At least they ought not to approach that distance. In other materials than wood, there is no motive for either carrying such compressile columns in *one length* across several points of attachment, nor for making them parallel-sided. It is only the *middle* thickness, halfway between two attachments, that need bear a certain ratio to their distance. If therefore this distance exceed 11 or 12 times the diameter of a cylinder large enough to satisfy the conditions about crushing, the strut or pillar must be enlarged at the centre beyond that diameter, (which is still sufficient at the ends,) but it is not necessary for this to add any material, because the centre may be either tubular or reduced externally, by 4 or more longitudinal recesses, to a cross or star section of no greater area than the ends.

While plain cylindric pillars no longer than the Doric proportion (in *iron*, but probably the Corinthian in stone) are found to have their strength simply dependent on area of plan, and no weaker when 6 that when 2 diameters high, thus showing the *whole* of their resistance to be active till crushed; any that are longer than the classic proportions (and not contrived as above) exert so little thereof that, by the best experiments, an increase of the excess in length as the arithmetical progression 1, 2, 3, 4, &c. seems to diminish the load that may be borne without flexure, in *geometrical* progression, to a half, a fourth, an eighth, a sixteenth, &c. of the absolute strength, or that of the same column stayed at proper intervals. Hence may be formed an idea of the enormous waste of material in columns and all compressed members when such as to be limited in quantity of matter by risk of *flexure*, i.e. when such are used as may bend *at all* with *any* load; and hence the danger of the system introduced by some iron engineers, of reducing, when the material is stronger, the *size* of supports instead of the *number*.

For the strength against cross-strain, which, we have seen, cannot be deduced (like the *stiffness* against it) from the above measure of direct strains, we can do no better than use the measures made of this as an independent element. These are embodied in the following table of the weights breaking when collected on its end, a bracket or arm one inch broad and deep and projecting a foot.

TABLE III.—TRANSVERSE STRENGTH.

Name of Wood.	lbs. to *break* a bracket 1 inch square and 1 foot long.
Acacia	155 E.
Ash, young tree	220 T.
——, old	160 B.; 157 E.
Beech	129 B.; 169 E.
Birch	129 E.
Cedar of Lebanon	103 T.
Chestnut, edible	112 E.
Deal, White, Norway	171 T.
——————, American	143 T.
——————, British	116 E.
Elm	135 E.
Fir, Yellow, Norway	193 T.
—————, Memel and Riga	135 T.
—————, British	80 T.
Larch	158 T.
Lombardy Poplar	81 E.
Mahogany, Honduras	159 T.
—————, Spanish	106 T.
Oak, English, young tree	241 T.; 140 B.; 170 E.
——————, old tree	109 T.
——, Canadian	144 B.
——Dantzig and Adriatic	120 B.
Pitch Pine	136 B.
Plane	150 E.
Red Pine	112 B.
Scotch Fir, British	145 T.; 98 E.
Teak	179 to 205 B.
Walnut	122 E.
Willow	91 T.

Authorities.—E. Ebbels. T. Tredgold. B. Barlow.

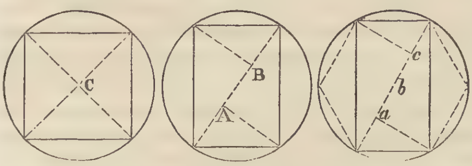
In applying this table it is only necessary to remember that the strength of rectangular beams is affected inversely by the length, directly by the breadth, and *doubly* by the depth. Therefore multiply the area in square inches by the depth (or the breadth by the depth *twice*), and this by the tabular number, and divide by the length in feet, to obtain the lbs. a bracket-beam will break with at its end. Distributed along its length, it will bear *twice* this load.

A spanning-beam, with the ends *loose*, bears, whether in its centre or distributed along it, twice what either half of it would bear as a bracket-beam with the weight on its end, or distributed along it; or as much as one quarter of its length projecting bracketwise.

A spanning-beam *fixed* at the ends, so as to bend there as much as in the centre, (with 3 curvatures like a wave) bears 3-fifths more; so that a long bar, having many supports, will lose 3-eighths of strength if the top fibres be cut where it crosses them.

To find the load a spanning beam will bear at any *other* point than the centre, call it P and the beam's ends A B. The load varies *inversely* as P A × P B; so that the load at any point P, is to that at C, as C A × C B is to P A × P B.

Owing to the strength varying, (with an equal length and load) as the width and *square* of the depth, while the deflection varies as the width and *cube* of the depth, the *strongest* beam that can be cut out of a given cylinder or tree is not the *stiffest*, nor are either of them the largest.



Largest. *Strongest.* *Stiffest.*

Fig. 2089. MODES OF SQUARING A TREE.

There is this relation, that as the corners of the largest (which is of course square) are found by drawing a diameter, bisecting it and drawing a perpendicular each way from the middle C; so, to get the strongest, *trisect* the diameter and draw perpendiculars opposite ways from the points A B; and to get the stiffest, *quadrisect* it at *a b c* and draw perpendiculars from *a* and *c*. The narrow sides of this last beam are also those of a regular *hexagon*, or equal to the radius of the circle.

Every one must perceive that a beam may have much matter removed from the top towards each end without losing any strength. The precise quantity which is superfluous in every beam of equal depth throughout, is the difference between the rectangle and an inscribed *semi-ellipse*, which we know has little more than 3-fourths of its area (·7854 the ratio of a circle's or ellipse's area to the enclosing square or oblong.) Of course, if we made beams for ourselves, instead of taking them out of a tree, we should omit this excess by making them semi-elliptical.

A rectangular bracket would appear to have still more useless matter hanging in the lower corner,—and theory confirms this by showing the effective mass, (when the weight is collected on the *end*) to be only *two-thirds* of the rectangle, viz. an inscribed *parabola* of which the top of the bracket is the axis. Architects cannot possibly add to the grace of this form of bracket, whether deep or shallow, and we see a near approach to it in all old brackets that carry such a weight, as those of machicolations, balconies with a stone parapet, and oriel-windows.

Brackets for a weight equally distributed from the wall to the end, have, however, when rectangular, *half* their matter superfluous, viz. all below a *straight line* drawn from the top front edge to the springing from the wall. This would be the form of one having everywhere the *breaking* depth at that point. Now we might at first think that an equal depth added everywhere, (so as to give the form of a similar but deeper bracket with the sharp front edge removed) would be in strict economy. But this amounts to adding a *rectangular* bracket, which we have seen to be excessive in the front and everywhere else if only sufficient at the wall. Let us add then the depths, at every point, of an unsuperfluous bracket, *i. e.* the parabolic one, and then we shall find we have, for the whole contour, a *hyperbola*, the well-known profile of those old *Doric capitals* and corbelling mouldings, designed to take an equally distributed weight of this kind.

Thus it will be seen that the application of mathematics to this subject has not, as yet, evolved anything new, or which had not been the general practice, ages ago, of the architects of most countries, who had been taught merely by instinctive observation, or what is termed "the eye." On the other hand, we must caution the reader against looking for the application of such principles in the material works of the age that investigates and explains them. The indefinable mass of motives and causes that, under the names of taste, fashion, feasibility, &c., govern modern material production, are, as Dr. Robison long ago remarked, so various, complicated, and foreign to nature and reason, that it is rare to find intelligible design in our professed architecture and engineering.

STRING-COURSE, a projecting course of masonry on the face of a wall, forming a *string*, or horizontal line. In Gothic architecture it consists of a series of mouldings; in Italian architecture it is a flat surface, either plain or enriched. String-courses serve to define the internal division of the building into separate stories; they also separate one tier of windows from another, and are useful in adding to the horizontal lines of the building. The upper surface of a string-course in Gothic architecture is usually splayed or sloped for the purpose of throwing off the rain.

STRONTIUM (Sr44), the metallic basis of the earth *strontia*, or *strontites*, which was first discovered in the state of carbonate, at Strontian, in Argyleshire. The metal may be obtained from its oxide by a process similar to that described under BARIUM. It is a white metal, heavy, oxidizable in the air, and decomposes water at ordinary temperatures. The *protoxide*, SrO, or *strontia*, may be prepared by decomposing the nitrate by heat; it resembles baryta, and forms a white hydrate soluble in water, and with a strong attraction for carbonic acid. There is also a *peroxide*, SrO . The native *carbonate* and *sulphate* are used in preparing the various salts of strontia. The *chloride*, SrCl, crystallizes in colourless needles or prisms, soluble in water, and also in alcohol, to the flame of which it imparts a crimson colour. The *nitrate*, SrO,NO_5, is chiefly used for making *red-fire*, as baryta is for making *green*.

For *red*-fire take 800 grains of dry nitrate of strontia, 225 of sulphur, 200 of chlorate of potash, and 50 of lamp-black. For *green*-fire, 450 grains of

dry nitrate of baryta, 150 of sulphur, 100 of chlorate of potash, 25 of lamp-black. The strontia or baryta-salt, the sulphur and the lamp-black are to be finely powdered and intimately mixed: the chlorate of potash in rather coarse powder may then be added without much rubbing, or the sulphur will cause it to explode. The red-fire composition is liable to spontaneous ignition.

STROP. See HONE.

STRYCHNIA, an alkaline base, which together with *Brucia*, is contained in *Nux vomica*, in *St. Ignatius bean*, and in *false augustura bark;* strychnia and brucia are associated with a peculiar acid, the *igasuric.* In order to procure strychnia, the seeds of nux vomica are boiled in dilute sulphuric acid until they are soft: they are then crushed, and the expressed liquid is mixed with an excess of hydrate of lime, which throws down the alkalis. The precipitate is boiled in spirits of wine of the sp. gr. 0·850, and filtered while hot. Strychnia and brucia are deposited together, but they may be separated by cold alcohol, which dissolves out the brucia. The strychnia when properly purified crystallizes in small brilliant octahedral crystals, which are transparent and colourless. The taste of strychnia is very bitter; it is slightly soluble in water, and is highly poisonous. It forms salts with acids, and its formula is $C_{44}H_{23}N_2O_4$. Brucia is distinguished from strychnia by its ready solubility in alchohol. It contains $C_{44}H_{25}N_2O_7$.

STUCCO. See MORTARS and CEMENTS.

SUBERIC ACID is formed by the action of nitric acid on *cork.* It contains $C_8H_6O_3 + HO$. Both this acid and *succinic* [see AMBER] may be produced by the long-continued action of nitric acid on stearic and mangaric acid. [See OILS AND FATS.] Suberic acid is a white crystalline powder, sparingly soluble in cold water, fusible and volatile by heat.

SUBLIMATION, a process of distillation by which a body is raised in vapour by means of heat, and condensed in a solid form. See DISTILLATION—ALEMBIC—CAMPHOR—SULPHUR, &c.

SUBSALT. See METAL.

SUCCINIC ACID. See AMBER.

SUGAR. The juice of a large number of vegetables owes its sweetness to the presence of sugar. This substance has from an early period of the world's history been used in some form or other as an article of food; indeed, the practice of sweetening food is more ancient than the knowledge of sugar. The ancients used honey for the purpose; and at a later period, when a sweet substance, which exuded from a species of cane, was used, it was termed *mel arundinaceum.* Dioscorides, in the first century, refers to a kind of honey produced by canes growing in India, and in Arabia Felix, and named *σάκχαρον*, or *sugar.* Pliny records the same fact, but remarks that it was used only in medicine. Sugar was not known in Northern Europe as an article of food, until the time of the Crusaders. The sugar-cane was introduced into Cyprus from Asia, and about the year 1148 is said to have been largely cultivated there; at which time it was transplanted to Madeira, and from thence, in 1506, to the West Indies. There is evidence that the sugar-cane was cultivated on the coasts of Andalusia before the invasion of the Arabs, in the middle of the fifteenth century. The Arabs had many sugar factories, and with them probably originated the art of boiling down the juice for the production of sugar. The refining of the raw product is of later date, and is referred to a Venetian. In the year 1597, a refinery existed in Dresden. Sugar-*candy* is mentioned in the *Alchemia* of Libavius in 1595. Up to the close of the seventeenth century, syrup and honey were used by the poorer classes in Germany for sugar; and it was not until tea and coffee had come into general use that sugar was regarded as one of the necessaries of life. In the year 1747, Margraf, a German chemist, discovered that cane sugar existed ready formed in the roots of many plants, especially in beet-root; but nearly half a century elapsed before any attempt was made to establish a factory of beet-root sugar; this was done by Achard, at Cumoom, in Silesia, not, however, with any great success. The first energetic impulse that was given to the manufacture was by Napoleon, who, anxious to ruin the colonial trade of Great Britain, ordered the blockade of the continent, and in order to supply the demand for sugar, which formed so important a part of our commerce, he offered premiums for the best methods of separating sugar from beet-root. The chemists of France exerted themselves with their accustomed method and skill. Extensive experiments were made on the cultivation of the beet-root, and the best methods of obtaining its juice, and extracting the sugar from it. Factories were soon at work, and the first sample of French beet-root sugar was conveyed at once to the emperor, who received it with joy, placed it under a glass case as one of the choicest ornaments of his drawing-room. He little thought that the extensive and valuable series of apparatus invented or improved by the French for the preparation of beet-root sugar, would, at a future day, be adopted by the English, and be the means of saving those very colonies, which had prospered in spite of his opposition, but which at a later period, chiefly by the renunciation of slave labour, had been brought to the verge of ruin.

SECTION I.—CHEMICAL RELATIONS OF SUGAR.

Sugar may be defined as a substance soluble in water, possessing a sweet taste, and capable of undergoing fermentation. There are two leading varieties of sugar: one the produce of the *Arundo saccharifera,* or sugar-cane; also found in beet-root, in the sap of certain species of maple, in the stems of palm, maize, &c., and is known as *crystalline* or *cane-sugar:* the other is contained in grapes, figs, plums, and fruits in general, and is known by the several names of *granular* or *grape sugar*, *glucose* or *sugar of fruits.* Fruit-sugar is however distinguished by some chemists from grape-sugar, as will be noticed more particularly hereafter. The property of submitting to the action of ferments and resolving itself into carbonic acid and alcohol is peculiar to fruit or grape-sugar; and when

other varieties of sugar undergo this remarkable process, they are by the action of ferments first converted into fruit or grape-sugar, and then undergo fermentation. [See FERMENTATION.] Cane-sugar is further distinguished from fruit or grape-sugar by its pure and powerful sweetness, and the facility with which it crystallizes. Grape-sugar is very inferior in sweetness; it crystallizes imperfectly, and is usually obtained in a granular state. It is accompanied in fruits by malic, citric, or tartaric acid. It may be produced artificially by the action of various agents on cane-sugar, and also upon lignin, starch, and gum. It forms the solid crystalline portion of *honey;* it also occurs in urine in the disease called *diabetes.* The term sugar has also been applied to *manna* or *mannite,* which occurs in the juice of some kinds of ash, in orchard trees, in celery, &c.: this kind of sugar, however, does not ferment. The juice of the *liquorice* root, and a few other substances, are also classed under sugar.

Cane-sugar.—Cane-sugar, when pure, is white and brittle: it becomes phosphorescent by friction, and a lump, on being broken, emits an electric spark which is visible in the dark. Its density is about 1·6. It dissolves in about 1-third of its weight of cold water, but in a much smaller quantity of boiling water. The *syrup* thus formed is viscid, and on being evaporated at a moderate heat, deposits fine crystals of *sugar-candy,* of which the usual crystalline form is a six-sided prism commonly flattened and terminated irregularly. The crystals are said to consist of 100 parts sugar, and 5·6 parts of water. A solution, saturated at 230°, forms in cooling a granular mass or *tablet,* but when the solution is rapidly boiled down until it acquires a tendency to vitreous fracture on cooling, or when fused at about 280°, or until a portion *feathers* or concretes on being thrown off from a stirrer, it may be poured out upon a marble or metal slab, and will form a transparent amorphous mass on cooling. This vitreous mass was formerly obtained by rapidly boiling down a concentrated solution of sugar in barley-water or sweet-wort, and hence the name of *barley-sugar* applied to sticks of it, formed by cutting the amorphous mass while hot into strips, rolling the strips into cylinders, and then giving a spiral twist to the cylinders. In this state the sugar is vitreous and transparent, but after some time, especially if exposed to air, it crystallizes, acquires a fibrous or granular texture, becomes opaque first on the surface, and then throughout the mass. Confectioners add a small quantity of vinegar or tartaric acid to the sugar, which retards this tendency to opacity. The show-sticks which are kept in the windows of grocers, &c. are made of coloured glass very accurately resembling the barley-sugar in its freshest and most transparent state. The tendency to crystallize is also removed by keeping the syrup for a long time at a temperature near its boiling point; but in such case a portion of the sugar probably passes into glucose.

Crystallized cane-sugar and barley-sugar consist of $C_{12}H_{11}O_{11}$: but if heated to temperatures between 300° and 400° they lose two equivalents of water, and become converted into *caramel,* $C_{12}H_9O_9$, a black deliquescent substance, without the sweet taste of sugar, not fermentable, and very soluble in water, to which it imparts a brown colour. Caramel acts the part of a feeble acid; it dissolves in alkalis, and forms black precipitates with baryta and oxide of lead. If caramel be further heated it loses water and forms a black insoluble product. If the temperature be still raised it disengages acid fumes, inflammable gases, and a black bulky charcoal remains. All these products may be obtained mixed by heating sugar rapidly.

The mineral acids, even when greatly diluted, and most of the organic acids, transform cane-sugar into a sugar which does not crystallize on being evaporated: and when submitted to the action of polarized light, it turns the plane of polarization to the *left,* whereas the action of cane-sugar is to turn it to the *right.* The acids which produce this remarkable change do not themselves undergo any alteration. It is probably the presence of acids in vegetable juices which converts their sugar into glucose; for in those cases where the juices are not acid the sugar belongs to the cane variety.

Cane-sugar combines with bases and forms in certain cases crystallizable compounds, termed *saccharates.* If a saturated solution of baryta-water be poured into boiling concentrated syrup, there is deposited on cooling a crystalline mass of *saccharate of baryta* ($BaO, C_{12}H_{11}O_{11}$). This salt may be heated to 424° without decomposition or loss of water; but it is readily decomposed by carbonic acid: the sugar enters again into solution, and the baryta is precipitated.

Two combinations of cane-sugar with lime may be formed: the first, by pouring a solution of sugar on slaked lime in excess; when a compound is formed which is very soluble when cold, and may be separated by filtration. If, however, the liquor be heated to boiling, the greater portion of this compound is precipitated, for it presents one of those exceptional cases in which a substance is less soluble at a high than at a low temperature. The precipitate may even be washed in boiling water and then be re-dissolved in cold water. This saccharide of lime, dried at 212°, consists of $3CaO.\ 2\ (C_{12}H_{11}O_{11})$. If, however, hydrate of lime be added in small portions to a concentrated solution of cane-sugar until it ceases to be dissolved, and alcohol be then poured in, a saccharide of lime is formed, consisting of $CaO.\ C_{12}H_{11}O_{11}$. The solutions of saccharides of lime have a strong alkaline reaction: they attract carbonic acid from the air, and there are formed on the sides of the vessel small transparent crystals of carbonate of lime.

If protoxide of lead, in a minutely divided state, be digested with a concentrated solution of sugar in excess, an insoluble saccharide of lead is formed, and the liquor retains a little oxide of lead in solution. The same insoluble compound is formed by pouring acetate of lead into syrup: saccharide of lead is then precipitated by ammonia. On leaving the liquor and the precipitate for some time in a warm place, the

precipitate assumes a crystalline texture. This saccharide of lead dried in vacuo consists of 2PbO. $C_{12}H_{10}O_{10}$. If heated to 350° it loses another equivalent of water, and becomes 2PbO. $C_{12}H_9O_9$. In the two states of dryness the saccharide of lead, on being decomposed by sulphuretted hydrogen, yields a saccharine liquor, which, on being evaporated, reproduces cane-sugar: so that the saccharine portion has not undergone any permanent change in losing 2 equivalents of water. Hence the formula for anhydrous cane-sugar is $C_{12}H_9O_9$, and for crystallized sugar $C_{12}H_9O_9$. 2HO.

If a concentrated solution of 1 part common salt and 4 parts of cane-sugar be evaporated crystals of sugar-candy will first be found; when these have been removed the mother liquor produces crystals which have both a sweet and a salt taste; they are soluble and deliquescent, and consist of NaCl. $2(C_{12}H_{11}O_{11}.)$ Similar combinations are formed with chloride of potassium and muriate of ammonia, and they all render the manufacturer of beet-root sugar liable to serious losses; for should the beet be grown near the sea, so as to imbibe much common salt, these various deliquescent compounds would remain in the molasses or refuse of the sugar. The loss is, indeed, much greater than at first sight appears: but it may be estimated by considering the equivalents of the substances concerned. Thus, if the composition of cane-sugar be represented by—

12 equivalents of carbon	or	C_{12}	= 72
11 ,, hydrogen	,,	H_{11}	= 11
11 ,, oxygen	,,	O_{11}	= 88
1 equivalent of sugar			= 171

and the composition of common salt by—

1 equivalent of sodium	or	Na	= 24
1 ,, chloride	,,	Cl	= 36
1 equivalent of common salt			= 60

it will be seen that the presence of a small quantity of salt in the saccharine juice may occasion the loss of a quantity of sugar 6 or 7 times greater; for 1 equivalent of salt = 60 unites with 2 equivalents of sugar = 342, and produces a compound = 402, the weight of which is 6½ times greater than the weight of the salt in the compound, and it also retains at least half of its weight of water saturated with sugar. A beet-root factory established at Naples, near the sea-shore, experienced heavy losses in consequence of employing beet-roots grown in the neighbouring fields; and we have also heard of similar losses in a German factory from the use of beet grown in a field in front of the graduation-house of the salt works at Manheim. A similar effect has been observed with respect to sugar-canes. Those which are grown near the sea make an inferior sugar to those grown inland; the quantity of melasses is greater, and the sugar more deliquescent. Mr. Kerr states,[1] that on the windward coast of Barbadoes he has tasted melasses as salt as if it had been mixed with strong brine.

The presence of sugar prevents the precipitation by alkalis of many metallic oxides, especially in the case of the salts of the sesquioxide of iron and of the oxide of copper, and the reason is, that the hydrates of these salts are soluble in a solution of sugar to which potash has been added.

The action of acids on cane-sugar has already been referred to. It is complex, and varies with their state of concentration and the ease with which they are decomposed and part with oxygen. Strong sulphuric acid decomposes cane-sugar with energy; charcoal, water, formic acid, and other products, are produced. If equal bulks of strong syrup and sulphuric acid be mixed, the mixture, when stirred, becomes brown, then black; it heats, boils up, and forms a solid, bulky magma of charcoal. The acid appears suddenly to abstract from the sugar the elements of water. When the sugar is dissolved in very dilute sulphuric acid and boiled, the effect is similar to the action of the acid upon starch, glucose being produced. Hydrochloric and several other acids produce the same effect. If the boiling be long continued, *sachulmine* or *sachulmic acid* is formed: these are brown or black uncrystallizable products, formed by the action of acids and alkalis upon several organic matters. Nitric acid, when very dilute, produces similar changes to the sulphuric, but when stronger it produces saccharic and oxalic acids, and at length these are resolved into carbonic acid and water.

If a mixture of 1 part cane-sugar and 8 parts quicklime be distilled in a glass retort, the mixture swells up at a certain temperature, gas is given off, and an oily liquid, which may be collected in a cooled receiver. This liquid, on being agitated with water, yields to it a product (C_3H_3O) which may be obtained in large quantities by distilling the acetates. It is termed *acetone*. The liquor which remains after the action of water is also oily. It consists of C_6H_5O; it boils at 130°, and is called *metacetone*.

Fruit or grape sugar.—Some chemists distinguish between the sugar of acid fruits, $C_{12}H_{12}O_{12}$, and *glucose* or *grape* sugar $C_{12}H_{14}O_{14}$. The former exists only in the acid juices of vegetables; chiefly fruits, such as grapes, currants, cherries, green gages, &c. It may be obtained by expressing the juice of these fruits, saturating the acids by means of chalk, boiling the juice with white of egg for the purpose of clarifying it, and then evaporating to dryness the filtered liquor. The sugar thus obtained resembles gum: it is very deliquescent; it dissolves in water and dilute alcohol: it enters immediately into fermentation on coming in contact with a ferment, and produces alcohol and carbonic acid. It exists ready formed in the ascending sap of the birch, and in the descending sap of the maple. Cane-sugar is readily transformed into fruit-sugar by the action of dilute acids even at ordinary temperatures, and the effect is produced by the organic acids, such as the tartaric, citric, malic, and oxalic. Cane-sugar always undergoes this change

(1) A Practical Treatise on the Cultivation of the Sugar-cane, and the Manufacture of Sugar, by Thomas Kerr, Planter, Antigua. London, 1851

under the action of ferments before it enters into fermentation, and becomes converted into alcohol and carbonic acid. It is generally supposed that the non-crystallizable sugar of all fruits is identical, but this is an assumption merely: further researches may lead to the distinction of various species. Fruit-sugar turns the plane of polarization to the left. Now, when the syrup of this sugar is left to itself for some time, it deposits small crystalline grains, to which, as Regnault remarks, the term *grape*-sugar has been improperly applied. These grains differ in composition from that of the sugar which produces them, since it contains the elements of 2 equivalents of water in addition; its formula being $C_{12}H_{14}O_{14}$. In dissolving these grains in water a syrup is produced unlike the original non-crystallizable syrup, which turned the plane of polarization to the left, while the solution of these crystalline grains turns it to the right, as in the case of cane-sugar. But it differs from cane-sugar, not only in its crystalline form, but in its behaviour towards chemical reagents, and in its rotary power. Cane-sugar, boiled with dilute acids, becomes converted into a sugar which turns the plane of polarization to the left, while grape-sugar undergoes no alteration, and continues to turn it towards the right.

The crystalline grains above-mentioned, properly called *grape*-sugar, $C_{12}H_{14}O_{14}$, form the white granules of sugar on the surface, and in the interior of dry raisins. If the pulp of these fruits, divested as much as possible of these white granules, be treated with water, a saccharine solution is obtained, which rotates to the left. Diabetic-sugar is identical with grape-sugar, as also is the sugar obtained by boiling starch in a weak solution of sulphuric acid, then neutralizing the acid with chalk, and evaporating the filtered liquor. The granules in honey consist of this glucose or grape-sugar, and the crust of sugar which forms on the surface of jams, jellies, and preserved fruits, consists of the same substance. In such case the cane-sugar used in making the preserves is changed by the acid of the fruits into a non-crystalline sugar, rotating to the left, and which in the course of time becomes converted into grape-sugar.

Grape-sugar crystallizes much less readily than cane-sugar, and always in confused masses: it is less soluble in water than cane-sugar, 1 part of sugar requiring 1½ part of water for solution. Hence its taste is less sweet than that of cane-sugar; 2 or 3 parts of the one being equivalent to 1 part of the other. Grape-sugar dissolves a little more freely in alcohol than cane-sugar. Solutions of grape-sugar turn the plane of polarization to the right. At the temperature of about 140° grape-sugar softens, and at 212° is completely liquid. At the latter temperature it loses 2 equivalents of water, and forms a new sugar, corresponding to $C_{12}H_{12}O_{12}$, similar to that of fruit-sugar, although it continues to turn the plane of polarization to the right. On evaporating a solution of this new sugar a pitch-like mass is obtained, but if left for a long time in contact with water, crystals of grape-sugar are formed. Grape-sugar is converted into caramel at high temperatures.

Grape-sugar combines less readily with bases than cane-sugar. When boiled with alkaline solutions the liquor becomes brown and evolves the odour of burnt sugar; acid products are formed which combine with the alkali. If slaked lime be added to a solution of grape-sugar, a large quantity of lime is dissolved; the liquor displays an alkaline reaction; it afterwards becomes neutral, and a precipitate is no longer produced by the action of carbonic acid. In such case the sugar is transformed into *glucic acid*, $C_8H_5O_5$, which forms soluble salts with most bases. Grape-sugar also forms a crystalline compound with common salt. Grape-sugar differs from cane-sugar in its action on metallic salts; it reduces their oxides either to a lower degree of oxidizement, or to the metallic state, so that some of these salts are useful tests of the presence of grape-sugar. If cane-sugar be added to a dilute solution of sulphate of copper, and the mixture be boiled, there is little or no change; but with grape-sugar the blue colour of the liquor becomes green, then yellowish or reddish brown, and suboxide of copper or metallic copper is precipitated. The best form of copper test for the presence of grape-sugar is the soda tartrate of copper, obtained by dissolving recently precipitated tartrate of copper in a solution of soda or carbonate of soda: it forms a deep blue liquor, which is decomposed at a boiling heat on the addition of a minute portion of grape-sugar, and a yellow hydrated dioxide of copper is thrown down, which becomes red on being filtered, washed, and dried. The soda tartrate of copper is prepared of such a strength that 100 cubic centimetres of the solution shall be discoloured when boiled with 1 gramme of grape-sugar. For this purpose, 100 cubic centimetres of the test solution are boiled in a porcelain capsule, and the solution of sugar is added to it from a graduated glass, and it is known that the volume of the saccharine solution which produces exact discoloration, contains exactly 1 gramme of sugar. This plan is also available for determining the quantity of cane-sugar in a solution; for which purpose the cane-sugar must first be converted into sugar, which turns the plane of polarization to the left, by boiling it with a little acid: the copper solution will then be acted on as in the former case. The proportions in which cane and grape-sugar are mixed, may also be ascertained by determining, first, the decolouring power of a simple solution of the mixture, and then the decolouring power acquired by an equal quantity of this mixture after the cane-sugar in the mixture has been boiled with an acid.[1]

The practical value of such a test will be better appreciated when it is stated that large quantities of grape-sugar are manufactured for the purpose of adulterating brown sugar. For this purpose potato-starch, and sago, are saccharized by the action of dilute sulphuric acid. 500 parts of starch are treated with 10 parts of acid in 1000 of water. The dilute acid is raised by means of steam to a temperature between 212° and 220°; and the starch, made into a

(1) For more minute directions on this subject, see Regnault, Cours de Chimie, tome iv.

thin cream with water at 112° to 130°, is allowed gradually to dribble into the dilute acid, the mixture being constantly stirred. The starch is immediately converted into dextrine, and in about 2½ hours the whole of the starch is used up, and in 15 to 25 minutes after, the saccharification is complete, the steam is shut off, the liquor transferred to another vat, and the process is repeated. In this second vat the acid of the liquor is saturated with powdered chalk, added gradually, to prevent an overflow from the effervescence. When the sulphate of lime has subsided, the clear liquor is drawn off and rapidly evaporated to the density of about 1·26 (30° Baumé); the sulphate is put on a strainer, and when drained, the remaining sugar is washed out of it. The resulting syrup is then left to deposit sulphate of lime, and is afterwards drawn off quite clear. In this condition it may be used as a source of alcohol, or for sweetening coloured liquors, and for many other purposes. In France it is largely used by the brewer in making the thin beer so much in vogue on the Continent. For some of its applications it requires to be deprived of colour, for which purpose it is filtered through animal charcoal. It is made solid by rapidly evaporating the syrup to the density of 1·45 (45° Baumé), and pouring it into shallow coolers, where it concretes. In Paris, glucose is prepared by Fouschard's method, in which the whole of the syrup is run off from the granulated sugar, which is afterwards dried upon thick tablets of plaster at a temperature of about 78°, and then pulverized. During these operations the disagreeable odour of potato oil is evolved to an annoying extent; this may be avoided by condensing the vapour, and applying the heat to the evaporation of the syrup, as will be more particularly explained hereafter.

Honey.—The substance secreted by the nectariferous glands of flowers is collected by bees, and converted by them into honey and wax. The former is used as food by the insects, and the surplus is stored up in waxen cells or *combs*, in the form of a yellow, viscid, and very sweet syrup. Honey, as already noticed, contains two kinds of sugar—one resembles the granular, or grape-sugar, the other is uncrystallizable. It also contains a yellow colouring matter, wax, gum, and sometimes mannite. The solid sugar may be obtained from granular honey by the action of strong alcohol, which dissolves the other ingredients. Honey may be whitened by boiling it with water, filtering, boiling with charcoal, again filtering, and evaporating the solution until it granulates on cooling.

Honey varies in its taste and smell with the age of the bees and the flowers on which they feed. The honey of Trebizond is remarkable for its deleterious qualities, and is collected from poisonous plants. There are also other examples of poisonous honey. The best honey is produced by a hive that has never swarmed, and is called *virgin* honey. The flavour of Narbonne honey, so much admired, is said to be due to the thyme and labiate flowers on which the bees feed; this is imitated by adding a sprig of rosemary to the honey from other places.

Honey is adulterated with flour; it may be detected by its insolubility in cold water, and by the blue colour produced by iodine. [See Wax.]

Manna-sugar, or *mannite*, occurs most largely in manna, but it also exists in beet-root, celery, asparagus, onions, and other sweet plants. It is found in the sap of the larch and other species of *pinus*; it exudes from their bark, and also from several species of ash, and it has also been met with in some kinds of fuci. The purest manna of commerce, *flake-manna*, is imported from Sicily and Calabria; it is of a buff colour, light and transparent; it has a slight odour, and a sweet but somewhat nauseous taste. Mannite is procured by boiling manna in alcohol; it crystallizes as the solution cools, and may be purified by pressure. It forms about 4-fifths of the best manna; the remainder being common sugar, and a peculiar yellowish extractive matter, which is thought to contain the aperient principle of manna. Mannite may be obtained from the fermented juice of beet-root, after the completion of the viscous fermentation; for which purpose it must be evaporated to a syrup; alcohol must be added to throw down mucilage, and on evaporating the filtered liquor mannite is deposited; it may be purified by repeated solution and crystallization. Celery-root also furnishes 6 or 8 per cent. of manna.

Mannite is a white or nearly white substance, very soluble in water; a concentrated aqueous solution concretes. It does not ferment even when much diluted, so that it may thus be separated from other varieties of sugar which are converted into alcohol, while the mannite remains undecomposed. Mannite is not very soluble in cold alcohol, but abundantly so at the temperature of ebullition. It fuses by heat without loss of weight, and concretes, on cooling, into a crystalline mass: at high temperatures it affords similar products to common sugar. It is converted by the action of nitric acid into saccharic and oxalic acids. Oxide of lead is dissolved in its aqueous solution. Crystallized mannite is said to contain $C_6H_7O_6$.

A kind of sugar has been discovered in several species of *agaricus* and other *fungi*, and also in *morels*; it is supposed to be identical with mannite.

Liquorice-sugar.—See Liquorice.

Section II.—The Sugar-cane, and the Manufacture of Raw Sugar.

The sugar-cane, *Saccharum officinarum*, is a perennial plant belonging to the family of the grasses. It rises to the height of from 6 to 15 feet and upwards, and attains a diameter of 1½ to 2 inches. It has a knotty stalk, and at each knot or joint is a leaf and an inner joint. The whole plant is shown in Fig. 2090, in which the *stole* s consists of 2 parts, the one s formed of several peculiar joints or *radicles*, varying in number from 5 to 7, placed very near together, having at their surface rows of small points, which are elements of roots. The radicles are separated from each other by a leaf called the *radicle leaf*. These joints form the first part, or *primitive stole*: but as this would not be alone sufficient for a nume-

rous filiation of joints, there are also several rows of points, or elements of roots, on the cane joints, which form, with the joints whence they issue, a secondary stole s″; they thus form roots until the joints are sufficiently numerous and strong to put forth and sustain those which are to follow them and form the stalk. This second part of the stole becomes very

Fig. 2090. THE SUGAR-CANE.

1. Young cane in its first development.
2. Cane of 10 or 12 months.
3. A cutting planted with the cane shooting forth.
4. Transverse section of sap-vessels.

strong, and seems to serve for the filiation of the remaining joints. The roots issue from the development of the sap vessels, which are disposed in concentric rays round each point on the surface of the joint. The sap vessels of the root, cut transversely, exhibit a circular surface of a cellular tissue, and are covered with a skin which is first white, and then brown or black. The roots are very slender, and almost cylindrical; about a foot in length, with a few short fibres at their extremities. The number of joints of the stalk or cane varies from 40 to 60, and even 80 in the Brazilian cane. In the Otaheite cane the joints are fewer and much further apart. The joints vary greatly in their dimensions. The knots are not simple enlargements, as in most reeds, but are rings from $\frac{1}{8}$ to $\frac{1}{4}$ inch wide; 4 or 5 rows of semitransparent points go round their circumference, [see Fig. 2092,] and a semitransparent line divides the outer from the inner joint. At the upper part of this is a slight circular hollow, called the *neck*, which is terminated by the leaf of the joint. The inner joint is entirely subordinate to the outer one in development and growth; in it the juice, after undergoing various modifications, becomes converted into crystalline sugar. On every joint is a bud enclosing the germ of a new cane. The sap vessels are shown in transverse and longitudinal sections of the cane in Figs. 2090, 2091.

Fig. 2091. LONGITUDINAL SECTION OF CANE.

The various parts of the cane grow and rise one upon the other, so that each particular part is a whole, and apparently pursues its course without reference to other parts. The bud contains the germ tightly enclosed within small leaves, and this germ is developed by the same laws in every part of the cane where a bud exists. If the head of one of the radicle knots be cut off in an early stage, its buds then receive the juices which would have nourished the head, and sometimes become sufficiently developed to throw out 20 joints. After removing the radicle leaves the first cane joint is usually discovered under that of the fifth knot, and is known by the appearance of the bud: if this be wanting it must be regarded as a radicle-knot, and the following joint will have the bud: or if not, then the next or seventh knot will have it. The germ of the first cane-joint springs from the centre of the last radicle-knot; which germ encloses the vital principle of the cane and of the generation of the joints. The first, in forming itself, becomes the matrix of the second, the second of the third, and so on. There is always a degree of difference in the various revolutions of each joint marked by the time of its generation, so that, as Mr. Porter well remarks, "the joints of the cane may be considered as concentric circles, the centre of which is always occupied by a point which, expanding into a circle itself, is replaced by a new point; circles, which rising successively one upon the other, enlarge and arrive in a given time at their greatest diameter."[1] Under fa-

(1) The Nature and Properties of the Sugar-cane, by G. R. Porter. Second Edition, 1843.

vourable circumstances it happens that, just after the first development of the cane joints, which form the secondary stole, the bud of the first of these joints throws out its radicle roots, and forms a second filiation on the first, as at *f f*, Fig. 2090; the bud of the first cane-joint of this second filiation also sometimes develops and forms a third; the second and the third soon become very nearly as forward as the first, and like it form canes. The first joint requires 4 or 5 months for its entire growth, and during this time 15 or 20 joints spring from it in succession, the decay of its leaf indicating the maturation of each joint. When the leaves of the first 2 or 3 joints have died away, there are about 12 or 15 leaves at the top disposed in the form of a fan. "If the cane be considered in its natural state it has at this period acquired all its growth, and arrived at the usual epoch of its flowering; if it blooms, the principle of life and generation passes entirely to the development of the parts of fructification; at this period, the joints which spring forth are deprived of their bud, and the sap vessels with which they are supplied pass into the leaf, whence it happens, that as the number of these vessels is constantly diminishing, the joints, in a similar manner, become longer, and their rind thinner. The last joint, which is called the *arrow*, is 4 or 5 feet long: it is terminated by a panicle of sterile flowers 18 or 20 inches high. If the period of flowering is delayed by cultivation, then the principle of life passes to the generation of new joints, and this continues till the sap vessels of the stole become woody, and do not afford a passage to the aqueous juices. Fig. 2092 is a representation of a magnified joint, with the skin removed to show the state and disposition of the radicle points.

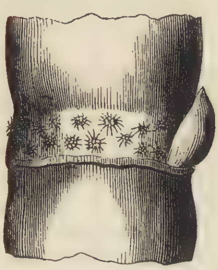


Fig. 2092.

The cultivator distinguishes 3 species of canes. 1. The *Créole* cane, which has dark green leaves, and a thin but very knotty stem; it is indigenous to India, and was transplanted thence to Sicily, the Canary Isles, the Antilles, and to South America. 2. The *Batavian*, or *striped* cane, which has a dense foliage, and is covered with purple stripes; it is chiefly cultivated in Java for the manufacture of rum. 3. The *Otaheite* cane grows most luxuriantly: it is the most juicy, and yields the largest product. This variety is chiefly cultivated in the West Indies and South America. It becomes ripe enough for the mill at 10 months, and is more hardy than the other varieties.

The sugar-cane being originally a bog plant, requires a moist nutritive soil, and a hot, tropical, or subtropical climate. It is propagated by slips or pieces of the stem with buds on them, and about 2 feet long. It takes from 12 to 16 months, according to the temperature, before it arrives at maturity. Towards the flowering season the leaves fall off, and the stem acquires a straw-yellow colour. Some planters cut the cane before the flowering season, but generally some weeks after. The plantations are so arranged that the various divisions of the fields may ripen in succession. The land should be well supplied with manure rich in nitrogen, but not containing much saline matter. After the harvest the roots strike again and produce a fresh crop of canes; but in about six years they require to be removed.

The time for cutting the canes varies, as already noticed, with the soil and season and the different varieties of the cane. The usual signs of maturity are a dry, smooth, brittle skin; a heavy cane; a grey pith, approaching to brown; sweet and glutinous juice. The canes should be cut in dry weather, or the juice will be diluted with an excess of water.

The development of the buds which form the secondary stole of a plant that has been cut, are named *rattoons*, and they are *first*, *second*, or *third*, &c., according to the age of the root which produces them. They diminish every year in length of joint and circumference, and although they have not the handsome appearance of the original plant, they yield much richer juice and produce finer sugar. The juice from the rattoons is also said to be more readily clarified than that from the plant cane.

The canes should be cut as close to the stole as possible, in order to give vigour to the rattoons that are to spring from the old root: besides this, the juice of the lower joints is the richest in the cane. The cane-top, with one joint of the cane, or two joints if not quite ripe, must also be cut off. The canes are tied up in bundles, and conveyed to the crushing-mill, particular attention being paid that the supply do not exceed the demand, otherwise the cut canes would ferment and spoil.

Fig. 2093. THE CANE HARVEST.

The depressed condition of our West India colonies has been referred quite as much to the defective culture of the cane, and the injurious methods of expressing and evaporating the juice, as to political causes. The land has hitherto been most imperfectly worked by hand-hoeing; a small hole is made for the cutting, which is but barely covered with earth; the expressed canes, instead of being returned to the land

as manure, are used as fuel; the cattle employed on the estates are also miserably neglected. These and other causes, which will be stated hereafter, are sufficient in themselves to produce failure, especially when it is considered that foreign planters have long adopted better modes of culture. Mr. Kerr recommends that the land should be deeply ploughed and thoroughly pulverized; that the cultivation should no longer be carried on by hand, but with implements, as in the best farming in England; and in putting in a plea for the better treatment of the cattle, he reminds the planter that the Psalmist, in praying for the prosperity of his people, asks emphatically, among other blessings, that "our oxen may be strong to labour, that there be no decay." Mr. Kerr states, that it is usual to plant the canes in parallel rows 6 feet apart, and the canes 4 feet from each other in the row. He recommends wider spaces, such as eight feet, between the rows; and states that in Barbadoes, in 1847, 90 acres of cane, planted 8 feet by 4, yielded 230 hogsheads of sugar. Some have even recommended to increase the distance to 10 feet, and others have advocated 8 feet square: that is, the canes in rows 8 feet apart and 8 feet distant from each other. It is also advisable to extend the planting over a period of 5 months; to begin early, so as to finish before the rainy season sets in. In addition also to the many advantages of returning the cane-trash to the land, Mr. Kerr states, that by spreading it over the spaces between the cane rows, it prevents the disastrous effects of severe droughts. The cheap rate at which coals can be sent from Great Britain to the colonies makes it desirable to abandon the use of cane-trash as fuel.

The juice of the sugar-cane consists of a nearly pure solution of sugar in water, with traces of albumen, about $\frac{7}{1000}$ of gum, and a peculiar substance resembling gluten or vegetable gelatine, which is deposited in large quantities in the vats in which sugar is fermented for making rum. The juice also contains of cerosin and a green vegetable wax, about $\frac{3}{100}$ to $\frac{4}{100}$. The mineral ingredients are similar to those in other plants and vegetable juices, and consist of the sulphates of lime and potash, chlorides of potassium and sodium, phosphate of lime, silica, &c. The juice is sometimes colourless, but generally yellow: it is made turbid by the presence of greyish globules of suspended matter. Its taste is agreeable, but rather insipid, and it has a peculiar balsamic odour. After the cane has been passed through the rollers and as much of its juice squeezed out as this imperfect method admits of, it is called *cane-straw, bagasse*, or *cane-trash*. It consists of—

	Martinique. Otaheite Cane.	Guadaloupe	Cuba. Creole Cane.
Water	72·1	27	65·9
Sugar	18·	17·8	17·7
Woody matter	9·9	9·8	16·4
Salts	—	0·4	——

The trash is used as fuel in evaporating the juice, as already stated. 100 parts of its ash consist of—

	Trinidad.	Berbice.
Silica	45·78	46·24
Phosphoric acid	3·75	8·12
Sulphuric acid	6·64	7·48
Chlorine	2·70	2·39
Lime	9·13	5·75
Magnesia	3·65	15·53
Potash	27·32	11·87
Soda	1·03	2·62

It is important to observe, that while the chemist has proved that as much as from 17 to 20 per cent. of crystalline cane-sugar exists in the cane or fresh juice, the sugar-boiler in the colonies does not obtain more than 7½ per cent., or less than one-half. His object is to convert the juice as speedily and with as few operations as possible into raw sugar; hence he has not been very active in improving on the old method of manufacture, which entails loss or deterioration of juice at every stage of the process: there is first a large loss in consequence of the imperfect method of expressing the juice from the cane, and, secondly, a chemical change in consequence of long exposure to the atmosphere at ordinary as well as at high temperatures, whereby the crystalline sugar becomes degraded into mucilaginous or non-crystalline sugar, commonly called *melasses* or *treacle*. The juice of the cane is purer, and contains twice as much sugar as that of beet-root, and yet the manufacturer of beet-root sugar manages, by means of improved processes and apparatus, to make the beet-root juice as productive as cane juice. It is true that the planter labours under certain disadvantages which may not be altogether compensated by a richer juice; the sugar cane contains 2 or 3 times as much woody fibre as the beet, which is soft and full of cells, while the cane is fibrous and spongy, and is surrounded by a hard integument difficult to submit to pressure. Moreover, in the climate of the sugar cane the ordinary temperature of the air is highly favourable to fermentation, so that the danger of decomposition is greater than in the case of the beet. The fact, however, still remains, that while science has been actively employed in perfecting the manufacture of beet-root sugar, she has, until recently, done little or nothing for the manufacture of cane-sugar; and now that attention has been fairly directed to the subject, in consequence of the depressed condition of our colonies, much of the beet-root apparatus is found to be admirably adapted to the wants of the colonial sugar boiler.

The original crushing apparatus of India was a kind of squeezing mortar, made out of the hollow trunk of a tamarind-tree, worked by a yoke of oxen, the pestle or stamper being a strong beam, 18 feet long, and rounded at the bottom so as to squeeze or crush the canes in the mortar. Squeezing-mills, similar to those used for expressing oils from seeds, [see OILS and FATS] were also used. There were also other forms of apparatus before rollers were introduced. Rollers of stone or iron were first used with the axes in a vertical position; but the horizontal was soon found to be more convenient and economical. A common form of mill is represented in Fig. 2094; the rollers are of cast-iron, 24 inches in

external diameter, with projecting rims to prevent the canes from spreading over the sides: they are worked by means of toothed-wheels attached to the axles. The canes are introduced from an inclined plane P

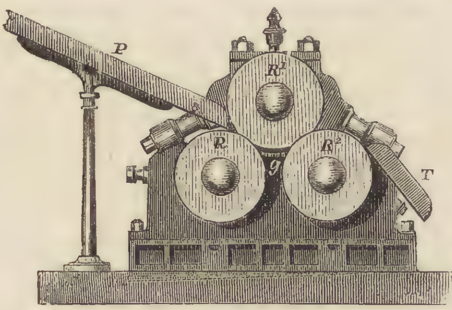


Fig. 2094. CANE MILL.

between the rollers R R^1; in some cases R is grooved to enable the roller more easily to carry the canes through. The crushed canes are guided by the plates *g* to the other side, between the rollers R^1 and R^2, where the fully crushed cane falls over the trough T. The juice collects in the channel below, and flows away to a reservoir. The cane should be crushed by the first pair of rollers, and the juice be expressed by the second pair, and the expressed spongy cane should not be allowed to come again in contact with the juice to reabsorb it. In some cases R^1 is grooved instead of R, and the distance between the smooth rollers should be less than that between the other two, or so narrow as barely to allow the cane to pass. The velocity of the rollers at their periphery is about 3½ feet per second.

Messrs. Pontifex and Wood have constructed some improved mills to be driven by steam in preference to water or wind, unless water-power be very abundant. The mill consists of 3 horizontal rollers as before, the space between the top roller and the bottom ones, against which the canes first impinge, being less than ¼ inch; while that between the top roller and the second bottom roller is only just sufficient to admit a piece of paper between them: this space, however, is determined by the quality of the cane, the thickness of the rind, &c. Motion is imparted to the top roller by means of a large cog-wheel at the back of the mill, and this communicates motion to the two bottom rollers by means of small toothed-wheels keyed on to the shaft of each roller. Slight grooves are sometimes made in the top roller, for the purpose of biting the canes more effectually in passing through the rollers; but as the grooves tend to tear the fibre of the cane, and to render it unfit for fuel, they are often omitted. The turn-plate between the two bottom rollers is perforated to allow the juice to pass through to the bottom bed-plate of the mill, which forms a sloping cistern, whence the juice flows into another cistern previous to its being clarified. The canes must be spread evenly on the feeding-tray, down which they pass through the first and second rollers, over the turn-plate, and through the second and third rollers. The distance between the rollers is regulated by screws, and in order to diminish the risk of fracture in the rollers, should the canes not be distributed evenly over the feeding-board, friction clutches are attached, so that when the strain on the rollers exceeds a certain amount they cease to act. Mr. Moore, in the office of Messrs. Pontifex and Wood, has invented what is called a *compensating* mill, in which the bushes, in which the two lower rollers revolve when the mill is overstrained, slide back in their frame-work, and thus increase the distance between the rolls, thereby adjusting the space between them to the work they have to perform, and ensuring the mill against fracture, and obtaining a more complete extraction of the juice: the required pressure is obtained on the canes by means of a heavily weighed lever.

Cane mills of great power are also made by Messrs. Neilson & Cô. and by Messrs. M'Onie & Mirrlees, of Glasgow. The former firm have lately sent to Cuba a mill with rollers 30 inches in diameter and 6 feet in length, capable of expressing 72 per cent. of the juice of the cane. The latter firm have mills in which the rollers are 28 inches in diameter and 5 feet long, and moving at the rate of 2½ revolutions per minute they are capable of furnishing from 2,500 to 3,000 gallons of juice per hour.

It is of great importance that the rollers should revolve slowly. The result of repeated experiments has shown that with a speed of 8 revolutions per minute, only 46 per cent. of juice has been obtained; while by reducing the speed of the same mill to 2½ revolutions, 70 per cent. of juice has been obtained.

Wind has been the usual power employed for driving the cane-mills. It is objectionable on account of its irregular velocity, which renders it inferior to any other description of power for crushing. It has been ascertained by comparing the results from 44 mills in Guadaloupe, driven by different kinds of power, that with windmills of inferior construction the cane mills produced only 50 per cent. of juice; with the ordinary windmills the yield was 56·4 per cent.; animal power gave 58·5; water power averaged 61·8; and steam 60·9.

From 12 to 14 tons of cane, fully ripe and in good condition, are required for the production of 1,500 gallons of juice, the quantity required for making a hogshead of sugar.

Mr. Bessemer objects to the roller-press, on the ground that the time allowed for the pressure on the cane is too short to displace all the fluid from the congeries of cells in which it is stored; and that, moreover, the amount of pressure on different parts of the cane is unequal, since the rind and the knobs are harder and more woody than the rest of the cane, and are therefore more strongly pressed than the intermediate parts, which are composed of soft cellular substance and juice, and that hence the chlorophyl and other matters are pressed out to mix with the juice. The new press proposed by Mr. Bessemer is represented in Fig. 2095. It consists of a crank-shaft with 3 throws on it; an oscillating steam cylinder, *St Cy*, and solid pistons on plungers *p p*, fitting in gun-metal tubes C C, perforated by small conical

holes, the interior of each hole being the smaller to prevent choking up. Above the tubes are hoppers *ff'*, down which the canes *s c* pass vertically, and as the plunger makes its stroke in the direction of the crank, the end of the plunger cuts off from the cane a piece equal to the height of the tube, while its further progress forces the newly-cut portion against a mass of already crushed cane *t*, whereby the greater part of the juice is forced out; but as the cane contains solid matter, the plunger, in finishing the stroke, must force the whole mass of crushed cane forwards a distance equal to that occupied by the solid portion of the newly interposed piece; which movement of the mass displaces at the open end of the tube an equal portion of the mass which occupies it. During the cutting off and pressing of this juice the plunger

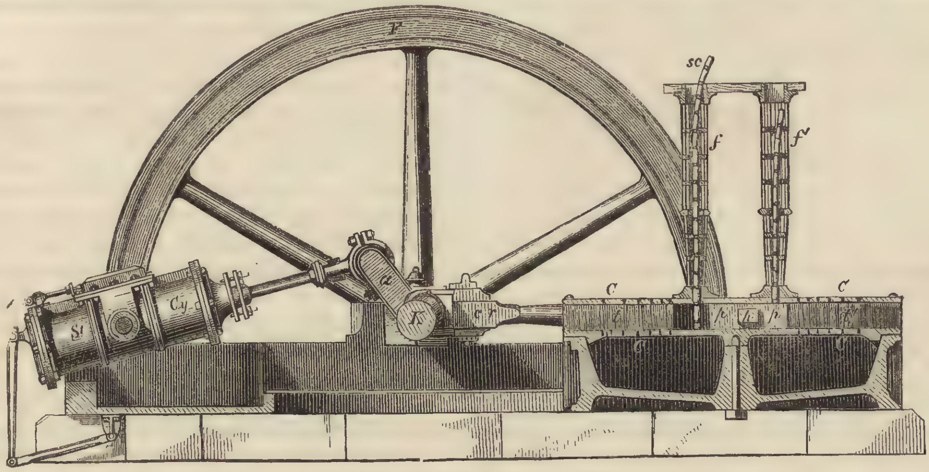


Fig. 2095. BESSEMER'S CANE PRESS.

will have moved forward under the hopper, and a portion of the cane within it will have fallen down within the tube. The reverse motion of the plunger also cuts off a length from it and forces it against the mass of cane trash *t'*, expressing the cane juice as before. In this way the reciprocating motion of the plunger acts on 2 pieces of cane at every stroke, and a similar operation also takes place at the same time in as many tubes as may be placed side by side over the cistern. In this cistern is a self-regulating heating apparatus for raising the juice to the temperature required for defecation within 2 minutes after its expression. The cane trash is produced in a condition favourable for fuel; it falls upon a carrier, and after being conveyed through a drying apparatus, is delivered at the furnace-door of the evaporating pans. It is stated that by this method the juice is larger in quantity, less coloured, and more free from small broken fragments, than when the pressure is performed by means of rollers.

There is no doubt that by the old method of expressing the juice by means of rollers a considerable portion of the sugar remains in the cane trash. Dupuy states that as much as 40 per cent. of sugar is thus lost. Something may be gained by distributing the canes more equally over the feed-board, and it has even been proposed to dip the crushed canes in water, and pass them a second time through the mill. The deficiency of water and wood on most plantations is an objection to this plan, which by diluting the juice would require wood for fuel, and the second passage of the cane through the rollers would so lacerate the cane as to render it unfit for producing the long flames required under the evaporating pans on the old method of concentrating the juice. It would also be an objection to Payen's proposal to employ 5 rollers R . . . R^5, Fig. 2096, enclosed under a hood of iron I, for the purpose of confining the steam which it is proposed to inject by the openings *s s* for the purpose of moistening the cane in its passage between the rollers. Indeed all

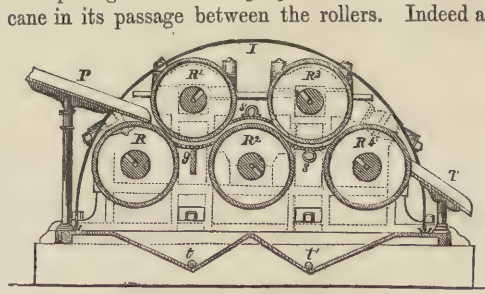


Fig. 2096. PAYEN'S CANE MILL.

plans for increasing the produce of the juice which leave the trash small and unfit for fuel have been rejected by the colonies. The scarcity of fuel is so great in some of the colonies, that it has even been proposed, instead of expressing the sugar-cane, to cut it in slices to dry them, and send them to Europe for manufacture into raw or refined sugar. But the very defect of fuel which led to this proposition would evidently be the chief barrier to carrying it out, since the fuel required for drying the canes would be wanting.

The true remedy for the enormous waste that attends the present mode of manufacturing raw sugar, must be found in the application of a regulated steam heat with coals for fuel, while the cane trash shall be left to its more legitimate application of manuring the land for future crops.

The waste of sugar by the old process has attracted

the notice of French as well as English writers. Thus Dumas states that of the 84 to 90 per cent. of juice in the fresh cane, only from $\frac{2}{3}$ds to $\frac{6}{7}$ths are obtained from the presses: that this $\frac{2}{3}$ds contain only 12 per cent. of the sugar actually existing in the fresh cane, 6 per cent. being left in the trash which is used as fuel: so that for every 80 millions of kilogrammes of raw sugar imported into France, 40 millions of kilogrammes have been burnt in producing them, the value of which, about 20 millions of francs, is actually thrown into the fire.

The *clarification* or *defecation* of the juice is produced by heat, which coagulates the albumen, and by the addition of lime, which neutralizes the acid, and renders some of the solid impurities insoluble. By the old method an arrangement called the *copper wall*, consisting of 5 pans, iron boilers, or *teaches*, as they are called, walled together in a row, and heated by one common fire, are used for the purpose. From the juice reservoir below the crushing mill, the juice is conducted into the clarifying pan, the fifth in the row, the largest, and farthest from the fire. It should be capable of holding the whole of the juice produced at one crushing, and should be ready to receive the juice almost as quickly as it is expressed. In some cases two copper walls are built under the same shed, as in Fig. 2097. The proper dose of milk of lime, or *temper*, as it is called, should be measured out by means of a vessel graduated into inches, each inch corresponding to 4½ oz. of milk of lime. Not less than 5, or more than 10 oz. are required to clarify 1,800 liters, or about $\frac{1}{1000}$ to $\frac{2}{1000}$ the entire weight of juice. When the proper temperature has been acquired, 10 liters of juice yield 15 grammes of precipitate, containing,

Gum resembling cherry gum	50·25
Green matter (chlorophyll)	10·05
Albumen, with particles of woody fibre	22·78
Phosphate of lime	3·35
Silica	14·07
	100·50

The phosphoric acid is originally present in the form of an acid salt; hence if copper vessels be used

Fig. 2097. THE BOILING HOUSE.

in clarifying, the metal is soon attacked and phosphate of copper formed: the lime converts this salt into a basic phosphate, which combines with silica and organic matters, and materially assists the precipitation of foreign ingredients. A dense impure scum collects on the surface, and is removed by skimming. The juice is then passed through the other 4 teaches, and heated until the evaporation is complete. During this process a large quantity of thick scum is removed by means of a perforated copper plate attached to a handle. The formation of this scum is a striking illustration of the defects of the system, for the scum consists of nearly pure sugar, decomposed by heat, together with the natural impurities of the juice: it is passed into the melasses cistern, and is chiefly used for making rum. As the bulk of juice is diminished by evaporation, so the teaches are usually made to diminish in size, the juice being passed from one to the other by a copper ladle or dipper worked by hand. The sugar is greatly injured by this repeated ladling and exposure in small quantities to the atmospheric air, and indeed the whole plan justifies the satirical remark, that it is "an elaborate and effectual means of converting pure sugar into melasses and scum." And Mr. Kerr remarks, that "the whole system, from the breaking up of the first clod of earth, to the rolling of the hogshead of sugar into the waggon, appears to have been expressly contrived for employing the greatest possible amount of labour."

When most of the scum has been removed in a compact form from the clarifier, the juice is ladled to the next pan, and as it diminishes in volume fresh juice is added. The pans are in some cases on different levels, so that the juice may be drawn off from one into the next below it, by means of a syphon; but the pans are not usually terraced, so that the juice has to be scooped from pan to pan. In the second pan the concentration begins; the boiling liquor throws up a scum, which the negroes collect and return to the clarifying vessel. In the last pan but one the juice is concentrated to 30° Baumé, and it is then passed into the last and smallest pan, which is situated directly over the fire. Here the boiling is tumultuous, in consequence of the formation of *panstone*, a deposit of lime consisting of—

Basic sulphate of lime	92·43
Carbonate of lime	1·35
Silica	4·70
Phosphate of copper	1·41
	99·89

with organic matter. The panstone forms more or less in all the boiling operations: it causes the juice often to be over-heated, the sugar to be burnt, and caramel to be formed, as when the incrustation cracks and the juice comes in contact with the hot metal. The crust is from time to time removed by heating the empty pan to redness, when, in consequence of the greater expansion of the metal, the crust breaks up and peels off. Sometimes the last and smallest copper contains a *skipping-teach*, a smaller vessel of the same shape, with a valve at the bottom worked by a handle. This vessel is let down by a crane into the pan, removes the sugar from it and conveys it to the coolers. In some cases, as shown in Fig. 2097, the

concentrated syrup is discharged down shoots into the coolers. Sometimes the term *teache*, or *tayche*, is applied only to this last vessel, in which the syrup is reduced to the *granulating* point, or sufficiently concentrated to separate on cooling into grains of sugar. The required consistency is ascertained by taking a small portion of the syrup upon the thumb, then bringing the forefinger in contact with it, and again separating them, noting the length to which a thread of syrup can be drawn before it breaks; if it extend to about half an inch in length, the sugar is judged to be fully boiled. This trial by the *touch* is supposed to have given the name of *teache* to the pan. The coolers are shallow open vessels, each capable of containing about a hogshead of sugar. They are of wood, with thick sides, that the cooling may be gradual. In about 24 hours the sugar grains, or forms into a soft mass of crystals, imbedded in melasses, which are separated in the *curing-house*, to which the soft sugar is removed. The sugar in the coolers is frequently stirred with iron rods, to produce a uniform temperature and consistency. The curing-house is a large building, the lower part of which is lined with lead, forming the melasses' reservoir. Over this, on an open framing, are placed the hogsheads or *potting-casks*. In the bottom of each cask are bored several holes an inch in diameter, into each of which is placed a plantain stalk, or a crushed cane, of sufficient length to reach to the top of the hogshead. The soft sugar being placed in these casks, the melasses gradually drain away through the spongy stalks or canes, leaving the crystalline portion tolerably dry. In 2 or 3 weeks, or 5 or 6 if the mass be mucilaginous and the grain small, it is fit for shipment; a further drainage of melasses takes place in the hold of the vessel, and even after this there are melasses entangled with the crystals of the raw sugar, to the injury of its quality.

Such is the *raw* sugar of commerce: it varies greatly in quality, but really consists of a crystalline flour of pure sugar, moistened throughout with melasses, often to the extent of one-third of its weight, and often more than the crystals can contain. Hence as it attracts moisture from the damp air of the vessel and becomes more liquid, it escapes from the crevices of the casks. It is calculated that about 12 per cent. of sugar is lost in this way from the English colonies alone, or about 27,000 tons annually.

In places where the sugar is not packed in hogsheads for the sea voyage, it is set to drain in the curing-house, in wooden moulds of deal. The syrup which drops from the moulds, or from the hogsheads, into a cistern, deposits on cooling a sugar, the grain of which resembles fine sand, and forming a layer on the bottom several inches in thickness. This inferior product is called by the French planters, *fond de citerne*. It averages about 10 per cent. of the raw sugar, depending on the temperature at which the sugar is placed in the moulds. It has a moist and smeary character, and is an admixture of various salts, of gelatinous silica, mucus or gum deposited from the refuse syrup, or mother-liquor, of the first crop of crystals.

The defects of the old system most plainly appear from the various modes adopted of calculating the loss. We have already given one or two estimates, and will conclude this section with one or two more. From every 1,000 parts of sugar-cane the old process yields from 60 to 80 parts raw sugar, and 25 to 30 of melasses; while according to chemical analysis the yield should be 180 to 200 parts of crystallized sugar. The following table has been drawn up from a large number of comparative results:—

In 1,000 parts—		
Raw Sugar	79	 73
Melasses	30	 27
Trash.....................	386	 395
Water	505	 505

Thus of the 180 to 200 parts of crystalline sugar in 1,000 parts of cane, there are obtained from 73 to 79 parts of raw sugar: 18 to 20 parts of melasses; cane trash, 28 to 33; and waste in the process of manufacture, from 48 to 61 parts.

Mr. Kerr also states that of the 1,500 gallons of juice required to make a hogshead of sugar netting 15 cwt. in the English market, the planter does not get a return of more than 6 per cent. of moist muscovado sugar, and that of very inferior quality.

Section III.—Improved System of Manufacturing Raw Sugar.

The various improvements in the rude process of manufacturing sugar described in the last section have for their objects the preservation of the juice from fermentation, and its concentration with as little agitation and exposure to the air, and at as low a temperature, as possible. Several proposals have been made for removing or diminishing the causes which lead to the rapid fermentation of the juice. Among other plans, Dr. Mitchell proposes to destroy the vitality of the glutinous fermenting matter, and to coagulate the albuminous substance in the tissue of the cane, by plunging the canes into some boiling liquid as soon as possible after they are cut. This plan would prevent the albumen, &c., from passing into the juice by expression. From some experiments made on this subject, it appears that a colourless juice was obtained; it was full of floating feculæ which immediately subsided, and the juice being decanted off and boiled down without the addition of any lime or temper, or any necessity for skimming, furnished a pure white sugar. By this process, the juice is diminished in quantity, but increased in density. Some of it was kept for 18 hours without undergoing any change.

M. Payen recommends the use of sulphurous acid or of bisulphite of lime for preventing the rapid fermentation of the juice. He advises that the ends of the canes be dipped into a solution of the bisulphite as soon as they are cut. An infusion of tannin or nut-galls has also been recommended for the separation of the deliquescent matter and soluble salts.

As the crushing-mill is generally on the ground, the juice is raised to the clarifying vessels by force-

pumps of peculiar construction, and with very little agitation. For this purpose it is admitted into an apparatus called a *monte-jus*, Fig. 2098, from which

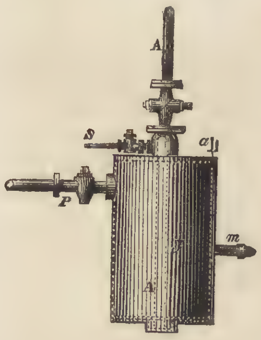


Fig. 2098.

it is forced up a pipe by the pressure of steam on the surface of the liquor. J is the vessel for receiving the juice, which passes into it by a pipe and cock P; S is a pipe for supplying steam for forcing the juice up A A; *a* is an air-cock, through which the air escapes on the admission of the juice: the pipe attached to this cock dips 2 or 3 inches below the top of the cylinder, so that the juice never rises above that height; the space above being filled with air, acts as a cushion between the steam and the cane-juice, thereby preventing the juice from being heated to the temperature of the steam; M is a man-hole. It will be seen that the pipe A is not only continued to the bottom of the receiving vessel, but dips into a sunken receptacle, by which means all the juice is collected; for it is of importance not to leave layers of juice at the bottoms of vessels to ferment and damage the fresh juice afterwards added.

Steam-heat is used for the clarifying vessel, into which the juice is raised by the monte-jus. This vessel consists of a hemispherical copper pan P, Fig. 2099, surrounded by a cast-iron jacket J, and steam is admitted into the space between the two, the supply being regulated by a valve *v*. On the top of the copper pan is fixed a *light course* L L, or copper band, from 15 to 18 inches deep, to prevent the scum from frothing over. The plug *p* in the bottom of the pan is furnished with two or three holes, through one of which the clarified juice passes down the hollow of

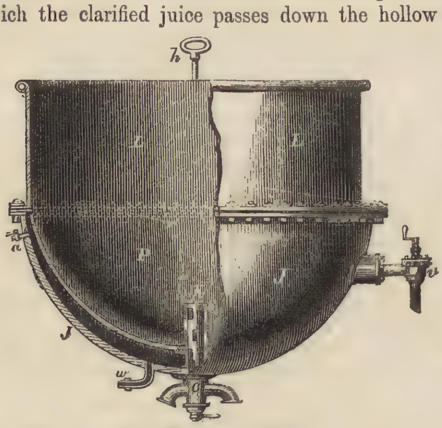


Fig. 2099. CLARIFIER.

the plug to the smaller channel of the two way cock C. When the clear liquor is run off, the plug is removed by means of the handle *h*, and the thick scum and sediment pass off through the larger way. The condensed steam passes away by the pipe *w*. *a* is a cock which is opened for a short time on the admission of steam, to allow the air to escape. The clarifier being filled with juice, steam is admitted and the temperature raised to 176° Fahr. Any particles which rise to the top of the liquor are skimmed off, and milk of lime is poured in in quantities just sufficient to neutralize the acid, which is ascertained by the frequent use of litmus paper. The heat is continued until there is formed a thickness of 3 or 4 inches of scum, consisting of most of the impurities of the juice. In about 10 or 12 minutes from the first application of heat the scum should be well formed and about to break up. The moment it begins to crack the steam is shut off, and the liquor being left for 15 to 20 minutes, the lighter impurities will have mostly risen to the surface, and the heavier ones sunk to the bottom, while between the two is a pale and beautifully clear liquor. The hollow plug which is ground into the hole in the bottom of the pan, is now turned by its long handle *h* so as to throw open a hole in the side 3 or 4 inches from the bottom, and consequently above the subsided impurities: by this opening the clear liquor escapes, and proceeds along the small channel of the two-way cock until scum begins to appear; the cock is then turned on to the larger way, the plug is altogether removed, and the heavy matters and scum pass out through the hole, and are conveyed to a cistern, placed in bags, and the juice squeezed out. The juice in the clarifier is never allowed to rise above 208° or 209°, or the impurities would become so mixed up with the juice as to be incapable of separation; a result which will also be attained unless the process be speedily conducted.

The clarified juice still contains matters in suspension, which require to be removed by filtration. The filters consist of fine copper-wire sieves in sets of 4 or more each, the one above fitting into the one below, the mesh of the lower sieves increasing in fineness. The bottom sieve has a flannel bag attached, for the separation of the finer impurities and the feculent matter. The flannel, or *bag-filter*, is sometimes used without the sieves in an arrangement shown in Fig. 2100, in which S is the cistern for containing the juice, *f f* the filter bags. The filtered sugar liquor is next passed through filters of bone-black or animal charcoal, in large slightly conical vessels of copper or iron, from 6 to 12 feet high, each furnished with a perforated false bottom over which a filtering cloth is spread. The cistern is sometimes closed in at the top in order to preserve the warmth of the liquor, and thus facilitate its passage through the filter. In filling

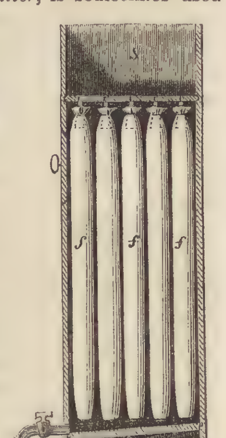


Fig. 2100.

in the bone-black, the first few inches are pressed compactly down; after which it is filled lightly, but

evenly, to within a short distance of the top, where a space is left for the accumulation of the cane juice. Fig. 2101 represents a vertical section of one of the charcoal filters used in France. Upon the false per-

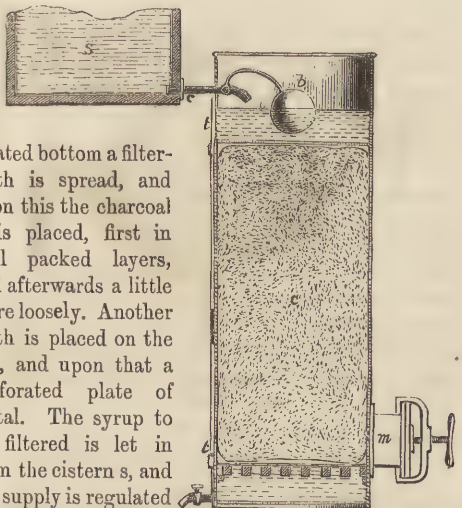


Fig. 2101.

forated bottom a filter-cloth is spread, and upon this the charcoal C is placed, first in well packed layers, and afterwards a little more loosely. Another cloth is placed on the top, and upon that a perforated plate of metal. The syrup to be filtered is let in from the cistern S, and the supply is regulated by a ball-cock *b c*, a certain quantity being always kept at the top of the filter to prevent the charcoal from drying and dividing into vertical channels or cracks, and forming what the French call *de fausses voies.* To allow the syrup to accumulate in the bottom reservoir of the filter, it is necessary to let the air escape, for which purpose the tube *t t* is provided. At *m* is a man-hole for cleaning out the filter when required. The object of filtering is to remove all vegetable colouring matter and any excess of lime that may have been accidentally added in the clarification, together with mineral salts, such as sulphate of lime, originally present in the juice. About 5 tons of animal charcoal are required for every 100 tons of sugar made. After this the charcoal is reburnt, and thus its useful properties are restored to it. See BONE.

The filtered liquor is now ready for evaporation, which according to the improved processes may be conducted either in the *vacuum-pan* or in open pans, containing a coil of steam-pipe. The usual plan is to concentrate the liquor in open pans to the density of 25° to 28° Baumé, up to which point it is not greatly acted on by the atmosphere. The evaporators used for this purpose are large iron vessels such as E, Fig. 2102, with copper pipes at the bottom bent round as shown in the plan, Fig. 2103, the extremities of which terminate in a straight gun-metal tube passing through stuffing-boxes H H: the pipe *s*, which conveys the steam, is at one end of the straight tube, and the pipe which discharges the condensed water at the other. By this arrangement the pipes can be raised up out of the vessel for the purpose of cleaning it thoroughly; for if the cane juice be allowed to hang about the pipes, it will become acid and infect the next charge. By means of the lever L the evaporator can be tilted into the position shown by the dotted lines, for the purpose of better running off the evaporated juice by the cock C. In these vessels the juice

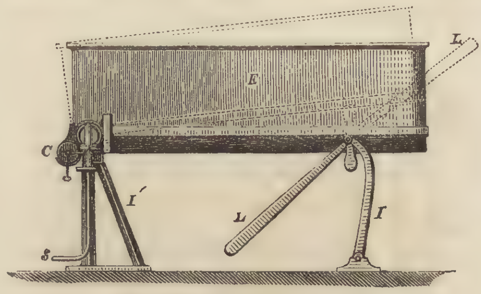


Fig. 2102. EVAPORATING PAN.
Elevation.

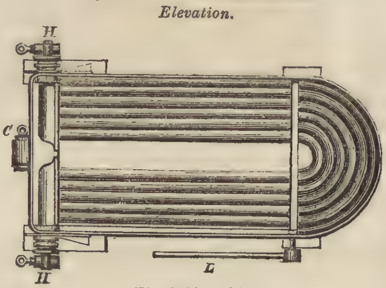


Fig. 2103. *Plan.*

is evaporated to about 27° B. before going into the vacuum-pan.

Another arrangement for concentrating the juice for the vacuum-pan is shown in Fig. 2104, and it possesses the great advantage of employing the waste steam of the vacuum-pan. It consists of a series of straight copper pipes *s s* placed one above the other, with the ends fixed in cast-iron boxes or united by curved end pieces as in the figure. The steam generated within the vacuum-pan is admitted within these pipes; and the weak juice which is to be evaporated is allowed to trickle down in a shower over these pipes; an arrangement which reminds us of the thorn-walls employed in Germany, for evaporating the weak brines used in the manufacture of common salt. [See SODIUM, Fig. 2009.] The weak juice is contained in a vat S, from which it passes along a pipe into a serrated trough *f*, and falling in drops from pipe to pipe it condenses the steam within, while itself becomes greatly heated, sends off vapour, and falls in a more concentrated form into the trough R, from whence it passes into a vat which feeds the vacuum-pan. There is, however, a remarkable adjustment of temperature in this apparatus, which is well adapted to the conditions of the process. As the cane-juice in passing over these pipes becomes more concentrated, and consequently more liable to injury from heat, the condensation of the steam within the pipes tends to mitigate the temperature, and to prevent the lower pipes from becoming too hot. The condensed water issues out through the pipe P, which is placed in connexion with a small air-pump, for the purpose of assisting the maintenance of the vacuum in the vacuum-pan, and the flow of steam along the pipes *s s* in the required direction. Thus, it will be seen that this apparatus is as ingenious as it is economical: the steam inside the

pipes parting with its latent heat to the juice on the outside, the one is evaporated and the other con-

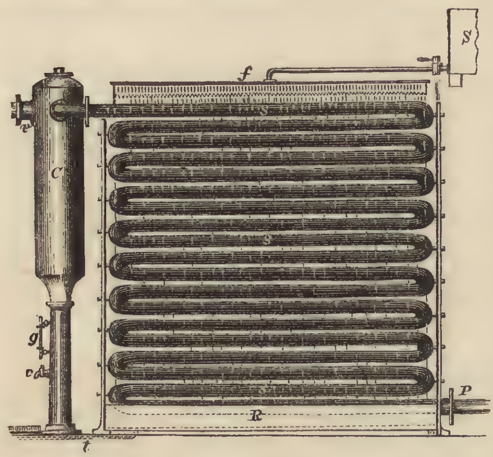


Fig. 2104. CONDENSER AND EVAPORATOR.

densed, thus enabling the vacuum-pan to perform twice as much work as it could otherwise get through.

The concentrated juice is next passed into the vacuum-pan, where the evaporation is completed; unless a sugar of very superior quality be required, in which case the syrup is slightly heated for the purpose of increasing its fluidity, and is again passed through the charcoal filters.

The vacuum-pan depends for its action on the principle that liquids boil at greatly reduced temperatures when relieved from the pressure of the atmosphere. [See EBULLITION.] The term *vacuum-pan*, however, is not very appropriate, for if all the air were removed at the commencement, the space would become rapidly filled with steam from the heated liquor, and an amount of pressure equal to that of the atmosphere be again established, unless means were taken for drawing off the vapour as fast as it formed, and even then an actual vacuum over the surface of a liquid could never be established. The vacuum-pan originally patented by Howard in 1812, has been of great value in the chemical arts, not only in the preparation of sugar, but also of medicinal extracts and other substances, the concentration of which, at their ordinary boiling points, was always dangerous, and generally led to the decomposition or deterioration of the vegetable juices. It has gone through a great variety of improvements since the date of its introduction. It is represented in its most approved form in a steel engraving, which is copied from the pan, manufactured by Messrs. Pontifex & Wood, which formed so conspicuous an object in the Great Exhibition. It is 8 feet in diameter, and is capable of boiling 80 tons of sugar in 24 hours. The section, Fig. 2105, will also assist the explanation. It consists of a copper pan, with a cast-iron jacket J, and arrangements for admitting steam between the two. Within the pan and corresponding with its curvature, is a worm or coil of copper pipe *p*, through which steam is passed for the purpose of boiling the juice. At the top of the pan and of the inner jacket is a copper dome D, fixed tightly by means of flanges. The steam generated in the vacuum-pan by the evapo-

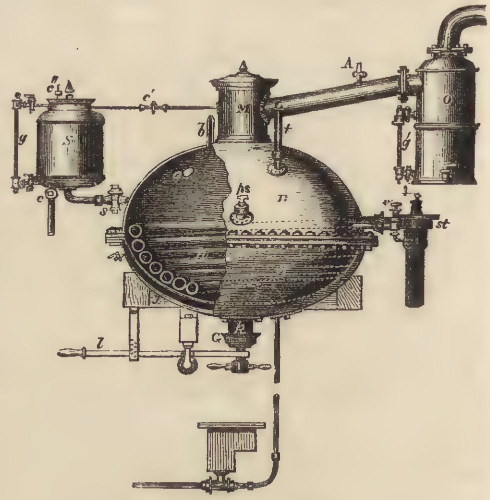
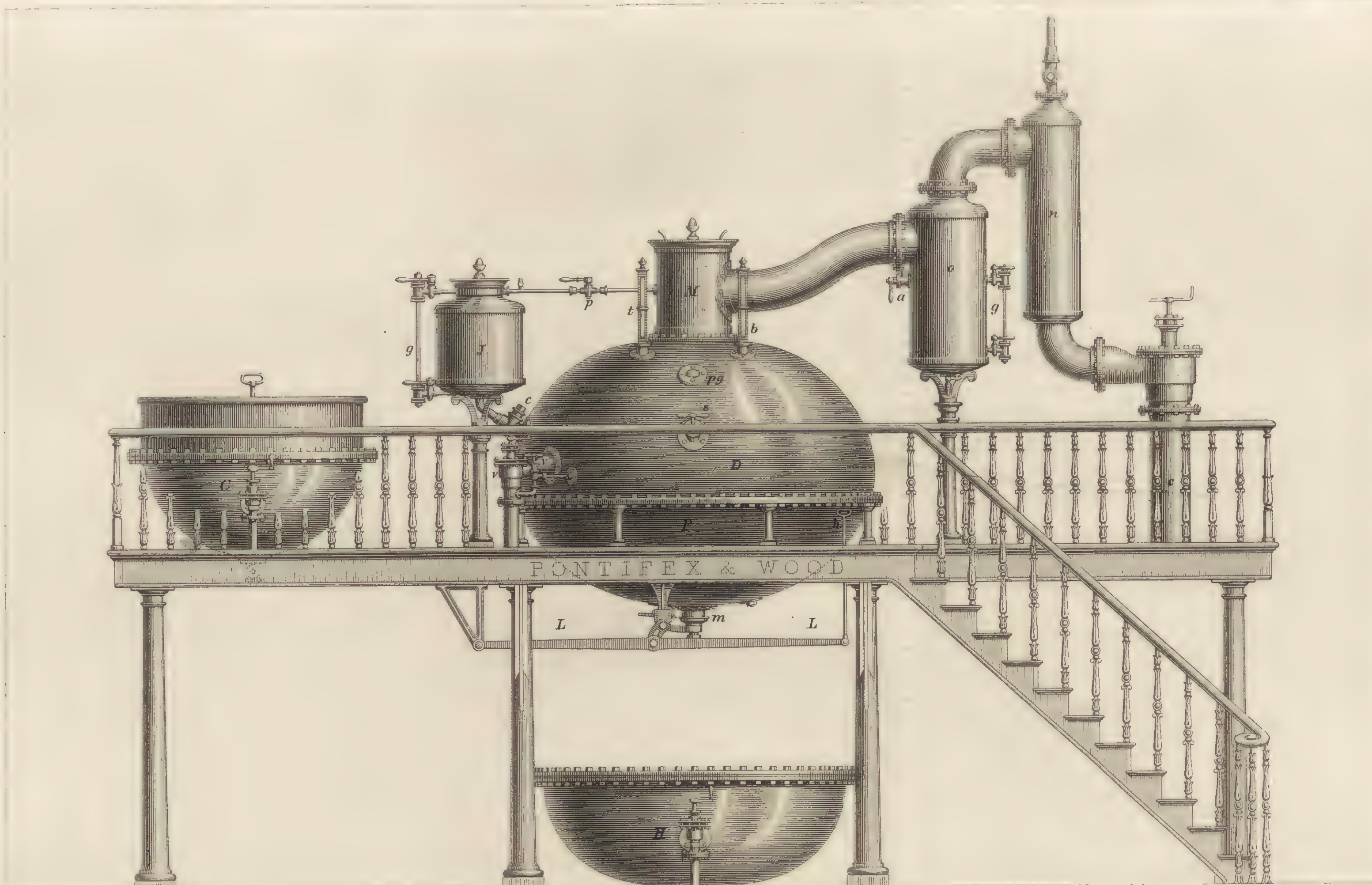


Fig. 2105. VACUUM-PAN.

ration of the juice, is removed by the condenser, Fig. 2104, already described, or the steam is drawn off into a condensing box, and condensed by the injection of cold water, as described under STEAM-ENGINE, Figs. 2043, 2044, 2053; by which means a partial vacuum is produced; and is further assisted by means of a powerful air-pump, which removes the water used in condensation, and also gets rid of the air which is carried in with the water. Now as air is far more difficult to remove than water, this method of condensation by injection is far inferior to that by the condenser, Fig. 2104, which does not require that water should come in contact with the steam, so that no air enters the pan; there is thus a saving of 40 to 50 per cent. of fuel, and consequently the vacuum-pan can be used in places where water is too scarce to command the large supply required for injection. There is also a saving in the size of the steam boilers required, in the freight, in the setting, and in the daily stoking. Besides this, the air-pump is not wanted, and thus the power required for working it is saved. A small air-pump is indeed generally attached to the condenser, in order the more quickly to get rid of the water formed by the condensation of steam in the pipes, and also to remove air from the pan at the commencement of the day's work. The condenser may be applied with advantage to steam-engines, producing a vacuum, according to the state of the atmosphere, of from 26 to 30½ inches of mercury; and when attached to high-pressure engines used in the manufacture of sugar, not only may the waste steam of the engine be employed in evaporating the weak cane juice in the same manner as the steam from the vacuum-pan; but it saves and returns to the boilers the condensed water in a hot and pure state; and lastly, by the addition of a small air-pump, it converts a *high-pressure* into a *condensing* engine, thus increasing the power of the engine and diminishing the cost of fuel required to work it.



SUGAR. VACUUM PAN.

We will now proceed with our description of the various parts of the vacuum-pan. The copper worm or coil of pipe through which steam passes for heating the juice, is marked *p;* the space between the pan and the jacket J is also occupied by steam. M is a man-hole with a movable gun-metal top ground into its collar, and is taken off for the purpose of repairing or cleaning the pan. *s t* is the valve for supplying steam to the worm; *v* is a smaller valve for admitting steam into the interior of the pan for cleansing. *p s* is the proof-stick for drawing out a sample of sugar during the process of evaporation, without disturbing the vacuum: it consists of a piston with a receptacle in it for receiving the sample of sugar, into which it is plunged by being passed down a barrel soldered into the dome, and dipping below the surface of the liquor; and the piston is so arranged that it can be drawn out of the barrel to a sufficient extent to allow the sample of syrup to be taken out without admitting air into the vacuum. By means of a cock of similar construction, a little piece of butter may be introduced into the pan, to modify the violent ebullition to which the liquor is sometimes liable. *t* is a thermometer for ascertaining the temperature at which the syrup within the pan is boiling; and *b* a barometer or vacuum gage for ascertaining the amount of pressure within the pan. S is a measure of the capacity of about 35 gallons, for regulating the quantity of juice admitted into the pan; it is furnished with a pipe and cock *c* dipping into a cistern below and which supplies the pan. *s* is the pipe and cock for conducting the measured juice into the pan. *g* is a glass gage partly enclosed in a brass tube for showing the quantity of juice in the measure; c' is a pipe and cock leading to the pan, through which the vacuum in the pan acts upon the juice in the cistern and draws it up into the measure, in filling which the cocks *c* and c' are opened and the juice is drawn up, and when the measure has received its proper quantity, these cocks are shut, and the cock *s* is opened; but as the cold liquor admitted into the measure will have condensed the vapour admitted into it from the pan, there will be a greater amount of rarefaction in the measure than in the pan when the cock c' is opened, so that juice will not flow into the pan until air is admitted into the measure, for which purpose the cock c'' in its cover is provided, and this being opened, the juice flows into the pan. O is an *overflow vessel* or *receiver* for catching any liquor that may boil over from the pan, the amount of the overflow being indicated by the gage g'; a cock at the bottom of O allows this juice to be racked off. A is a small air-cock in the arm-pipe, which conducts the vapour from the pan to the condenser. In the dome of the pan are small peep-glasses, *e*, one on each side, so that by looking through one, the other affords sufficient light to watch the progress of the boiling in the pan. The sugar is run out of the pan by a gun-metal saucer G, ground into a socket *k* attached to the pan; the saucer is raised or lowered by means of the lever *l*. In some cases a cock is substituted for the saucer, and is brought by means of a windlass wheel within the control of the sugar-boiler, who can work it without having to leave the vacuum-pan stage. The handle *h* in the steel-engraving is intended for a similar object.

In addition to the above apparatus, there is an expansion vessel, for reducing the pressure of the steam to the point required in the vacuum-pan. It is a large cylinder of plate-iron C, Fig. 2106, into which

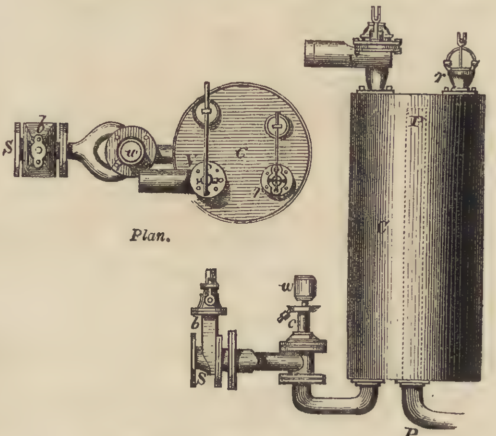


Fig. 2106. EXPANSION VESSEL.

steam is admitted by the pipe S. At the top of the vessel is a valve V, loaded to the required pressure, through which steam escapes as soon as the pressure in the vessel rises above that point; the expanded steam is then led away to the vacuum-pan through the pipe P. *b* is a valve for opening or closing the way between the boilers and the expansion vessel. *r* is a small safety self-regulating valve. Messrs. Pontifex & Wood have improved on the above common method of expanding, which occasions a waste of all the steam above the required pressure, by the contrivance of a peculiar valve *c*, which is a hollow cylinder, containing a solid piston or plunger loaded to the required weight by *w*, so that as soon as the pressure exceeds the counter-balancing weight, the piston, against the bottom of which the steam acts, rises and partially closes a valve which regulates the admission of the steam, and when the pressure is so reduced that the weight is able to force the piston down, the valve is again fully opened.

In operating with the vacuum-pan the syrup is run in as quickly as possible, until the whole of the heating surface is covered: the steam is then turned on, and the temperature of from 180° to 190° maintained. When the syrup begins to granulate or form crystals the temperature is lowered to 160°, and just before the evaporation is completed, and the sugar ready to be let out, the temperature is reduced to 145°, or the lowest temperature at which proof-sugar boils at 3 inches below a perfect vacuum. The sugar-boiler takes out a sample of syrup by means of the proof-stick, and drawing it out against the light between his finger and thumb, ascertains that the crystals are in a sufficiently forward state: he then adds another measure-full of syrup to the pan, and the same process is repeated until the whole charge is admitted.

As each successive measure-full is admitted, the crystals increase in size to the end of the operation, those first formed acting as nuclei. A *skip* or pan-full of concentrated sugar should be made in from $1\frac{1}{4}$ to 2 or $2\frac{1}{2}$ hours from the commencement of boiling. If fine grained, the sugar requires a greater quantity of syrup to be admitted at each charge of the measure, and *vice versâ*. The concentrated juice, or proof-sugar, consisting of a large number of small crystals floating in syrup, is let down at 145° through a cock or valve in the bottom of the pan into a vessel called the *heater*, which consists of a copper pan with an iron jacket, and is similar to the clarifier, except that it is larger and has no light course on the top. It is furnished with a condense-box to allow the condensed steam to escape without loss of steam: this is a cast-iron box with a pipe at the bottom, in which is a valve attached to a float-stone: as the water enters the box the float-stone rises, opens the valve, and allows the water to escape; and when the float-stone again falls the valve is closed, thus preventing the escape of the steam admitted into the box with the condensed water.

In the heater the sugar is raised to 180°, or that best adapted to the hardening and completing the formation of the crystals. During the heating the sugar is stirred with wooden oars to promote granulation: it is ladled or run out into buckets or scoops, and hence poured into moulds, or small cones, F or B, Fig. 2107: the hole at the bottom of each cone is plugged with paper, which is not removed until the

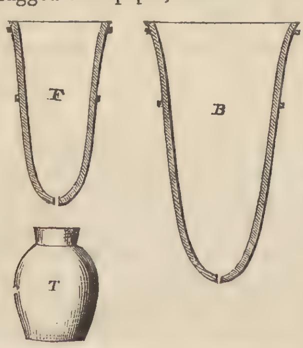


Fig. 2107. MOULDS AND TREACLE-JAR.

morning after the day on which the moulds are filled. The mould-room is kept at the temperature of 100° for 3 or 4 days, during which time the sugar undergoes the process of *liquoring:* this consists in pouring on the top of the moulds a solution of pure sugar, which percolates through and carries with it the small quantity of colouring matter not previously removed. The drainings are collected in pots or treacle-jars, T, Fig. 2107, which support the moulds, and are boiled down with other refuse of the sugar-house into an inferior sugar. A separate pot for each mould is not to be commended, for if the pots are not well washed out there is a liability to fermentation, or *smear*, as it is called, and this will spread through the whole establishment with astonishing rapidity, and when once formed, is difficult to eradicate. We have heard of a sugar-refiner who had to work up the whole of his stock twice before this evil could be got rid of. The use of pots is, in many cases, superseded by supporting the moulds in frames, as in Fig. 2101, and allowing them to drain into gutters or false floors of thin sheet-copper, sloping towards a centre constructed under the main floor, where the syrup is conveyed by copper pipes to a cistern. It has been proposed to expedite the drain-

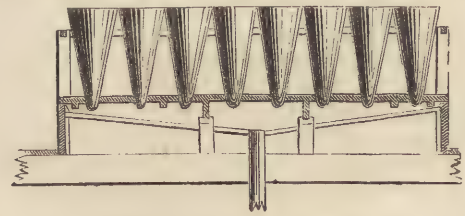


Fig. 2108. MOULDS IN FRAMES.

ing of the moulds by connecting their nozzles with a pipe communicating with an air-pump; but in such an arrangement the sugar would be liable to be drawn through the perforations with the syrup. Several other plans on the vacuum principle have also been proposed.

When the sugar is properly drained it is taken out of the moulds in the form of loaves, which are trimmed to shape, placed in a stove or hot room of the temperature of 130° to 140°, and when the moisture has evaporated, they are fit for the market. The sugar thus obtained is half the weight of that let down into the heater from the vacuum-pan: the remainder consisting of moisture or drainings. A very small proportion of the syrup that drains away consists of uncrystallizable sugar or treacle in which all the impurities of the loaf are accumulated. If the improved operations have been well conducted the produce is equal to refined sugar, and there is no practical reason why perfectly white sugar should not be produced from the canes at one operation. The sugar, as it comes direct from the canes, contains only 1·5 per cent. of impurities, whereas the sugar-refiners in England have to operate on a material considerably deteriorated by previous mismanagement. Fiscal regulations have hitherto interfered with colonial improvement, a larger duty having been imposed on sugar above a certain standard, thus actually discouraging the production of white sugar at its natural seat of manufacture, and encouraging slovenly and bad work. In the islands of Java and Cuba, where the best machinery has been introduced, from 30 to 40 per cent. is now saved in the quantity of sugar produced, and its market value is increased from 5*s.* to 10*s.* per cwt.

British Guiana is also a striking example of the good results of improved processes and machinery in the manufacture of sugar. Some years ago it was feared that this colony must have ceased to grow sugar in consequence of not being able to compete with Barbados and Antigua, where the new machinery was in full play. No sooner, however, did Antigua join in the march of improvement, than her fortunes began to change. In 1851 the quantity of sugar made with improved apparatus amounted to 7,170 hhds., or upwards of $\frac{1}{7}$th of the produce of the colony. In 1852 the quantity was 10,380 hhds., and in 1853 the quantity is expected to be 13,000 or 14,000 hhds., or as large a proportion of refined sugar to the quantity manufactured as in the United States

where no duties are levied. What is wanted to complete the improvements which are now going on in our colonies is one uniform rate of duty on sugars, without any reference to their fineness; and it has been proposed to reduce the duties to the uniform rate of 10*s.* per cwt., a proposition which will probably be adopted. In anticipation of this result a joint-stock company has been formed in Barbados, with a capital of 40,000*l.*; and they propose to purchase the canes of the small planters, and manufacture sugar on a large scale with all the modern improvements. A great saving is thus expected to arise from the separation of the agricultural from the manufacturing part of the trade. Jamaica is said to have been behindhand in the adoption of improved machinery, but that the vacuum-pan is now becoming general on all the plantations. It is stated that in several parts of the West Indies, by employing the cane trash as a manure instead of burning it as fuel, with the addition also of a moderate quantity of guano, the yield of the cane has doubled and even trebled, 4 tons of sugar per acre having been made even under the present wasteful system.[1] The planters are now also becoming aware of the advantage of packing up a dry crystalline grain instead of sugar made wet and spongy by the deliquescent molasses, which, gradually oozing out of the casks, washes the sugar away with it, and is pumped out of the hold of the vessel into the sea.

Section IV.—Manufacture of Refined Sugar.

The defects in the manufacture of raw sugar led to the contrivance of certain methods of separating the colouring matter and the melasses from the crystalline portion, and introduced the art of the sugar-refiner, which has long been an important branch of industry in Great Britain. It is evident that the refining of sugar in this country instead of the colonies must be disadvantageous in many respects, for the sugar has to be redissolved in water, which must be again evaporated, and during this process the sugar is again exposed to the risk of deterioration, and a certain portion of crystalline sugar destroyed. There has been indeed a less amount of loss since the sugar refiners have adopted the improved apparatus and processes of the beet-root sugar factories. Previous to this the only purifying material employed was animal albumen in the form of bullock's blood, which of course formed a new source of deterioration in the sugar; while so little was known as to the science of the operation, that the amount of success depended chiefly on the skill of the workman. Since the introduction of animal charcoal and steam heat the operation of refining has been conducted with the precision of a scientific process. There is, however, this additional objection, that the raw material is constantly changing in quality, and there is no certain and ready means of testing the amount of pure uncrystallized sugar in raw cane sugar. The relative amount of colouring matter may be ascertained by making experiments on a small scale with animal charcoal. The optical test may also be adopted. It must be constantly borne in mind that the great object of all improvements in the manufacture, is the production of a better quality of raw sugar. The colonial manufacturer will probably never be able to produce refined sugar at once from the juice, but this is the standard of perfection which he should endeavour to attain as closely as possible.

The raw sugar from the West Indies, America, and the East Indies is chiefly imported in cases; from Jamaica, Domingo, and St. Croix in hogsheads; from Manilla and Mauritius in double sacks plaited or woven from the leaves of reeds. The quality varies in all degrees, from white Havannah, almost equal to loaf sugar, to the dark brown, moist, sticky, and smeary characters of the worst varieties. The more coarsely granular, the harder, drier and whiter, the greater is the value of the sugar, and the better is it adapted to bear carriage.

The first operation at the refiner's is to empty the cases or hogsheads on the clean floor. A quantity of sugar adheres to the staves, which is large in proportion as the sugar is sticky. It is loosened and removed by means of steam, for which purpose the hogshead is inverted over an arched copper surface in the form of a flat inverted boiler, in the centre of which is a steam jet pipe, and the edge is turned up to form a channel. In a few minutes the steam condenses on the sides of the cask, and becomes saturated with sugar; the solution collects in the channel and flows into the pan in which the great bulk of sugar is dissolved. The sugar is first passed through a sieve to remove lumps, and a sufficient quantity of water is added to the melting-pan to make up about 30 per cent. including that from the hogsheads, and steam is applied to dissolve the sugar as quickly as possible, for which purpose a perforated pipe is fixed at the bottom of the pan, and when the steam is turned on it *blows up* through the water and completes the solution; hence these pans are sometimes called *blow-up cisterns.*[2] The concentrated solution, or *melting* as it is called, is allowed to flow into the clarifying-pan, while the melting-pan is directly supplied with a fresh charge, so that one melting-pan or blow-up cistern is sufficient. While being dissolved in this pan, a small portion of blood and some lime water are added for the purpose of clarifying the solution and neutralizing the acid. The solution is agitated by a mechanical stirrer, or by 2 or 3 men with oars. Only about $\frac{1}{2}$ per cent. of blood is used, and its action is materially assisted by 3, 4 or 6 per cent. of ground

(1) The absence of nitrogenous manures in the colonies has led to their extensive importation from Europe, such as dried blood, flesh and fish refuse, shreds of woollen cloth, animal black, &c. The use of blood as a manure formerly attracted the rats in large numbers, and not only was the blood consumed but the roots of the canes were injured. The ravages of these animals were prevented by mixing charcoal dust and fat with the blood.

(2) Mr. Finzel has patented a plan for melting or blowing up in vacuo. The advantages are, that exposure to air and heat being avoided none of the sugar is converted into melasses, and the solution is effected with great rapidity.

animal charcoal.[1] The blood must be uniformly mixed first with a small quantity of saccharine liquor, and this is stirred into the pan, the temperature being kept below 168°, or that at which albumen coagulates;

Figs. 2109. BLOW-UP CISTERNS.

but this low temperature is maintained only for a few minutes, when, to prevent the decomposition of the blood, steam is fully admitted, and the solution rapidly urged to the boiling point. The use of the albumen dispersed throughout the solution is to entangle and so collect the minute mechanical impurities, and then, by its coagulation, it forms into large connected flocks, easily separable by strainers. It forms with the charcoal a thick compact scum, quite distinct from the clear liquor below which has been partially decoloured by the action of the charcoal. It still, however, contains suspended impurities coated with albumen, and hence the liquor is passed through a

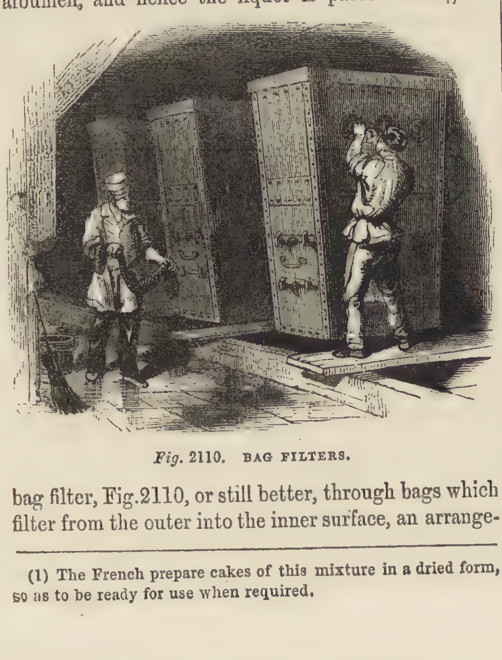


Fig. 2110. BAG FILTERS.

bag filter, Fig.2110, or still better, through bags which filter from the outer into the inner surface, an arrangement which allows the filters to be more easily cleaned, and their wear is not so rapid. In the interior of these bags basket work is placed to keep the sides from collapsing. The filtration into these

Fig. 2111. CHARCOAL FILTERS.

bags is so rapid that an ordinary charge of 7 cwt. in the melting-pan can be passed through in from 15 to 20 minutes. The filtered liquor is collected in a cistern, whence it is passed through the charcoal filters, which in the course of 15 to 20 hours discolour a quantity of syrup containing 4 times as much sugar as there is charcoal in the filters. The syrup, now called *liquor*, is collected in another reservoir which supplies the boiler.

The boiling is conducted either in open pans heated by steam, or, what is by far the more common, in vacuum-pans: the liquor is evaporated to the density of 42° or 43° B., at a temperature varying from 230° to nearly 240°. In fact, the liquor is so concentrated that the sugar is only held in solution by the high temperature, so that, on cooling, a rapid crystallization takes place, which produces that uniform fine grain such as is required in loaf-sugar. It was formerly the practice to produce a slow crystallization by evaporating the water in a hot chamber, instead of a rapid crystallization by simply lowering the temperature of the concentrated syrup. The former practice was slow, and required a good deal of space. But in order to produce this fine grain, or irregular conglomeration of crystals, the liquor must be poured into the moulds at a certain temperature, just when the crystals have begun to form; and as the liquor leaves the vacuum-pan at too low a temperature for the purpose, it is heated up in a vessel furnished with a false bottom for the admission of steam, which is again the convenient source of heat, and then cooled to the granulating point in vessels capable of holding the entire quantity of liquor boiled in a day. As the temperature falls, the formation of crystals of too large a size is prevented by stirring: at a certain fixed temperature the syrup is poured into the moulds, which, as usual, are of the funnel or sugar-loaf form; for the purpose of assisting the separation of the mother liquor, there is a hole in the point

(1) The French prepare cakes of this mixture in a dried form, so as to be ready for use when required.

of each mould, which is at first closed up. The larger the bulk of syrup the slower is the cooling, and the more regular the crystallization. For bad syrups, which crystallize with greater difficulty, large bastard moulds B, Fig. 2107, are used; but the smaller ones F are employed with syrups which are inclined to produce too coarse a grain. The moulds were formerly made of porous clay, which, however, absorbed much syrup, and occasioned trouble in cleaning: iron was, therefore, substituted: the iron moulds are coated either with varnish or glaze, or painted with white lead paint. They are arranged in rows in the crystallizing-rooms in treacle-jars T, Fig. 2107, or on wooden supports, under which the pots are placed. They are filled with syrup from

Fig. 2112. FILLING THE MOULDS.

the coolers by means of large copper scoops, by a number of men who pass rapidly to and fro, filling and emptying their scoops, and they so contrive as not to fill any mould at once, but to let each mould receive syrup from different layers of liquor in the cooler. They are filled on the lowest floor, and are raised to the upper floors either by manual labour, or

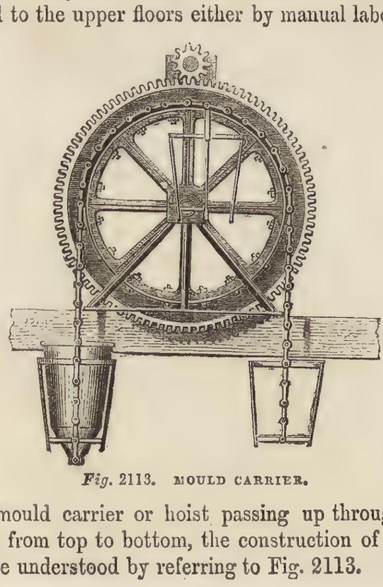


Fig. 2113. MOULD CARRIER.

by a mould carrier or hoist passing up through the house from top to bottom, the construction of which will be understood by referring to Fig. 2113. As the sugar tends to crystallize first at the sides, especially if they are rough, and also to form large crystals on the surface, the syrup is stirred up in the moulds with a wooden spatula or knife to detach it from the sides, and this process is repeated after half an hour. The crystals thus become equally diffused through the thick syrup, and afford points for a uniform crystallization, which is complete in from 14 to 18 days. In this way a compact net-work of small crystals is formed, the meshes being filled up with the mother liquor or saturated solution. This is impure in proportion as the crystals are pure, but being viscid it drains off with difficulty, even although assisted by the warm atmosphere of the room, which is maintained at 75° and upwards. The plugs are removed from the points of the moulds, and they are left to drain for 24 hours. When the running abates the loaves are loosened by inverting the mould and detaching the sugar: the syrup then drains off more freely. The *green syrup* thus separated is collected or allowed to run together from a connected system of gutters, and is removed every day; or the moulds are arranged over wooden pipes lined with zinc, with openings in the upper surface to catch the drippings. In about 4 days or more the melasses are tolerably well separated, except at the point of the loaf, which still retains a little colour. The loaves are now taken out of the moulds; the brown points are cut off for remelting, and the loaves are trimmed and dried.

The above process does not afford loaf-sugar of very good white colour, or of a dry and firm texture: a little of the coloured syrup is still entangled in the interstices of the crystals; so that instead of, or in addition to, the above process, that of *claying* is resorted to. This is a method of washing out the remains of the coloured syrup by the following contrivance:—White pottery clay, not so fat as to retain a very large quantity of water, is washed, in order to separate the soluble ingredients, and then placed on the sugar, while still in the moulds, in the form of a uniform thin paste. Before the application of the clay each loaf is removed from the mould, the solid crust formed at the point is removed, and the upper layer at the base is loosened and scooped out, in order to form a cavity in the centre for the reception of the clay paste, which is put on 1 lb. at a time in a layer about 4 lines thick. The action is as follows:—The water from the clay drives the melasses before it, and soon becomes converted into a saturated solution of pure sugar by dissolving some of the crystals. The other portions of the water form still purer solutions, and they all sink through the loaf, expelling the mother liquor, and the brown colour descending towards the point gradually disappears. In this way the crystalline net-work of nearly pure sugar in the mould becomes impregnated with a pure solution of sugar, which, in drying, cements the crystals together, and imparts the requisite solidity to the loaf. The clay is generally removed once during the operation, and the syrup which drains off is termed *clayed* syrup.

The use of clay is now superseded by a pure saturated solution of sugar: it has the advantage of not dissolving any of the crystals of the loaf (because it is already saturated at the temperature of the mould), and it gets rid of the trouble and inconvenience attending the use of clay; it leaves a pure surface, and introduces no foreign ingredient into the loaf. The saturated solution is poured in at the top of the mould, left for some time, and when it is observed to trickle slowly from the point, the moulds are inverted for a short time that the residue of the clay-syrup collected in the apex may be diffused through the loaf, and give it a uniform colour: or the point may be knocked off, and a new top be afterwards produced, by turning it between crooked knives. The loaves are separated from the moulds by a blow on the edge, and are again placed with their points down, that the syrup between the surface of the loaf and the side of the mould may drain off. This done, they are placed upright and covered with the mould until ready to be removed for drying, first, at the ordinary temperature of the room for a day, and then in a drying chamber, at 77°, which is gradually raised to 122°. The sugar thus produced is of the first quality. The secondary products, consisting of the various syrups, are added to water for the purpose of dissolving the next charge of raw sugar, or they are mostly treated alone for the different varieties of bastard sugar. The last portions retain so large a quantity of syrup, that they are too soft for *loaf*, and are sold as *moist* sugar. The inferior syrups are much more slowly cooled: they are run into bastard moulds B, Fig. 2107, of 1 cwt. each, and are crystallized at a higher temperature in proportion as the sugar is less pure. The first quality mould contains about 30 lbs. weight of the granulated mass, and from this about 10 lbs. of green syrup will drain off, leaving 20 lbs. of wet sugar, which, by drying without claying, are reduced to 17 lbs., but if clayed to 11 lbs., but this is sugar of the first quality. In a bastard mould 60 lbs. of granulated sugar of the second quality, 25 lbs. of melasses will drop from it, leaving 35 lbs. of unclayed moist sugar, or 32 lbs. when dry, which, after claying and drying, produces 17 lbs. as the marketable product. The time required, from the melting of the raw sugar to the completion of the dry loaf, is from 35 to 40 days, and longer for the inferior qualities.

Many attempts have been made to shorten the time required for refining, or, in other words, to expel more rapidly the melasses from between the crystals. The temperature of the rooms has been increased: the pressure of the atmosphere has been called into play, by placing the point of the mould over a long column of melasses, so as to form a Torricellian vacuum which, from the great density of treacle, may be had with a vertical height of about 23 feet, and into this vacuum the melasses is expelled from the mould by atmospheric pressure. Derosne has proposed, instead of the saturated solution of sugar in the claying process, to employ alcohol of the density of 33° or 34°, which dissolves the syrup readily, while the crystals are not much affected by it. The plan is quite successful, and is expeditious, 6 days only being required instead of from 35 to 40: but the danger of fire and the high price of alcohol in this country, are sufficient objections to its adoption.

Another chemical mode of refining has been proposed by Dr. Scoffern, which, if it could be carried out without danger, would be of great value, since the use of animal charcoal and of filtration would be rendered unnecessary. The proposal is to separate all the colouring and foreign matter in the saccharine juice by means of a solution of basic acetate of lead, the oxide of lead in which combines with these matters, and precipitates them in an insoluble form; the excess of lead-salt employed by saturating the saccharine solution, after the separation of the lead precipitate, with sulphurous acid gas, which produces with the lead an insoluble sulphite of lead, the excess of gas being removed by simple boiling. The above ingenious process is not new. The late Professor Daniell, who was connected in early life with the sugar-refining trade, discovered this, or an analogous process, with acetate of lead; but being aware of its danger he kept it in his own hands. For many years after he became professor of chemistry at King's College, he was in the habit of attending certain sugar refineries every week, where he gave out the proper quantity of acetate of lead (which at other times he kept under lock and key), and when the sugar had been refined by its means, he again attended to test the syrup, to be quite sure that the whole of the poisonous salt had been removed. In the hands of such a man there could of course be no danger to the public from the use of a poisonous salt as a means to an end; but in careless or unskilful hands it might lead to disastrous results: hence the process is not to be recommended.[1]

It has been proposed to separate the melasses or noncrystalline portion of the sugar from the crystalline, by the action of centrifugal force, for which purpose the sugar, properly prepared for the purpose, is put into a cylinder of wire gauze and rapidly rotated, when the sugar being driven against the sides of the drum, the melasses escape through the meshes, and are carried off through a cock in the outer case. In this way the crystals may be brought to any degree

(1) In the report of the British Association for the advancement of Science for the year 1850 is a communication from Dr. Scoffern, from which it appears that on the southern coast of Spain, in a region limited by Almeria on the east and Malaga on the west, bounded on the north by mountain ranges, and on the south by the Mediterranean, is a tract of land in which the date-palm, indigo, cotton, and sugar-cane flourish with vigour. "The sugar-cane first introduced by the Arab conquerors is not only consumed in large quantities as a dessert, but also gives rise to a considerable manufacture of raw and refined sugar." Dr. Scoffern has introduced his process into this district, and although operating with the old and imperfect apparatus, he describes it as being successful; "sulphurous acid being an agent most antagonistic to fermentation," and "the sulphite of lead being most easily removed, and were it to remain, no injury could supervene, inasmuch as this agent is as harmless as chalk." In the discussion that followed, Professor Christison stated, that caution was necessary in accepting as a fact the statement, that the presence of a small quantity of sulphite of lead in sugar would not prove injurious to health.

of whiteness, but cannot of course be made into loaves. The arrangement of the apparatus is shown in Fig. 2114, in which D is the drum or cylinder, which may be of sheet metal or wire gauze: I, an external casing of cast-iron; *s*, the shaft to which the drum is attached, and is driven by the usual gearing G with very moderate power, less than that of 1-horse. The whole machine is $4\frac{1}{2}$ feet in diameter; it contains about 2 cwt. of sugar at each charge, which is refined in about 8 minutes.

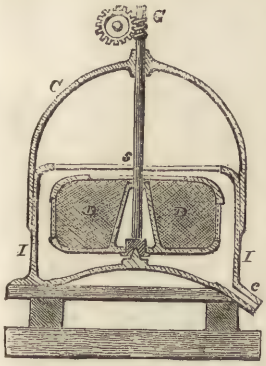


Fig. 2114.

Mr. Bessemer has patented a variety of machines and improved processes connected with the manufacture of sugar: one is for a centrifugal filtering machine for separating fragments of cane, &c. from the juice after being expressed from the canes, and also the coagulated matters after defecation. The purified juice is also evaporated by a centrifugal evaporator, and the result of a number of most ingenious arrangements, is the production of a beautiful highly crystalline grain, or what is known in the market as *crushed sugar;* but it is stated that it does not realize the extra price required to compensate for the smaller quantity produced.

The manufacture of *sugar-candy* may be regarded as a branch of the refiner's art. The large crystals of sugar, which pass by this name, are prepared from a syrup clarified with a less quantity of charcoal-powder than is usual, and not passed through the filter. The crystals, which are coloured, inclose a certain portion of non-crystalline sugar. If the candy is required for the sake of its solvent action on the mucous membrane of the throat, it should not be prepared from clarified or clayed sugar. To increase its mucilaginous and sticky properties it should, after clarification with white of egg, be boiled over an open fire and not in vacuo; and for the darker kinds of sugar-candy a higher temperature should be employed than for the lighter. The syrup is set to crystallize in a copper vessel with smooth sides, and contracted towards the bottom that the crystals may be easily removed. At the sides are several small rows of holes at equal heights, through which strings are passed which serve as nuclei to the crystals. The copper is filled up above the strings, and is then placed in a drying chamber at the temperature of from 104° to 122°. As the syrup cools and evaporates, solid crystals are slowly formed, partly on the surface, but chiefly on the strings and the sides. The crystals on the surface are frequently broken up. In 6 or 8 days the crystallization is complete; the vessel is inverted, the syrup drains off, and when the dropping ceases the crystals are removed and dried.

A description of sugar, called *stamped sugar,* is prepared from the inferior qualities, generally lump, in such a manner as to have the shape and appearance of first quality refined. Moist soft lump sugar is grated or mechanically divided, and the flour passed through a sieve: while still moist it is stamped in layers into a first quality mould, from which it is immediately removed and dried.'

SECTION V.—MANUFACTURE OF BEET-ROOT SUGAR.

A short notice of the cultivation of beet-root is given under the head BEET. There are a large number of varieties of this plant, of which the following have been used in sugar factories; viz. I. The *large field beet,* the *disette* of the French, and the *mangel wurzel* of the Germans: the flesh and skin are white, as are also the leaf-stalks: the bulb is almost *cylindrical,* and protrudes very much out of the ground, sometimes as much as 15 inches, while 4 or 5 only are covered with soil: this is the largest of all the varieties, single bulbs weighing 25 lbs. and upwards each. A bulb of 34 lbs. is noticed by Knapp. This large size is not to be commended, since the watery character of the bulb increases with the weight. The juice rarely exceeds 6° Baumé in density; there is a sub-variety of a reddish colour, the cross section of which exhibits an alternation of white and rose coloured rings. It is known as *Long red mangels.* The blood-red garden beet is regarded as the link between the first and second varieties. II. The second group is represented by the white *Silesian* beet: it has a somewhat *pear-shaped* form, white flesh and skin, and occasionally rose-red rings in the flesh; it is smaller than the preceding varieties, the largest roots generally averaging 5 lbs.; the juice is pure; it abounds in sugar, and is more easily operated on by the sugar manufacturer than the other varieties, on account of the absence of salts and other ingredients which exert an injurious action on the sugar in boiling, and diminish the value of the produce or impede the process. It is hard and resists putrefaction, so that the bulb can be kept for a time with but little loss. When fully ripe and properly cultivated the juice usually averages 7° of Baumé, but it often exceeds 8°, and has been known to be much higher. There are 3 chief varieties of the White Silesian, distinguished by the colour of a ring presented by a cross section of the crown close to the bulb. These are—1. The *collet rose,* with a rose-red ring. 2. The *collet vert,* with a green ring. 3. The *collet jaune,* which has a yellow ring. The *spindle* or *pear-shaped* beet of the second group is linked to the third by the variety called the *Quedlinburg beet.* Its form is between the pear and spindle shape; the skin is rose-red, the flesh white, and somewhat softer than the Silesian: the average density of its juice is about 7° B. III. The type of the group of the third form, or *globular,* is the *yellow globe mangel wurzel,* or *Castelnaudary beet.* It is pear-shaped, approaching to globular; the skin and flesh are yellow, sometimes passing into orange; leaf-stalks yellowish green; the flesh soft and juicy;

(1) We have to express our acknowledgments to Messrs. Fairrie, of Whitechapel, for information on the subject of refining, and for permission to take sketches for our engravings

and the density of its juice from 5° to 7° B. It grows to a much larger size than the Silesian beet. Four sub-varieties of it have been distinguished; one of which is the *white globe beet.* The *Siberian* beet belongs to the third group; it is of a flattened pear-shape, spread out almost like a plate; the flesh is white, or occasionally rose-red; the leaf-stalk is white: this variety is softer than the Silesian; it yields more juice, but of a lower specific gravity. The bulb grows nearly altogether out of the soil, which is a disadvantage, since the parts of a bulb which are exposed to the full action of the sun contain less sugar than that portion which is covered by the soil.

All the varieties of beet tend to change their colour, and to develop a red colour in the skin, and a slight rose tinge in the flesh, especially the white and yellow varieties. They do not appear to differ in chemical composition. They all contain sugar, and may be used in its manufacture; but the variety most employed for the purpose is the *White Silesian,* or *sugar beet,* the *collet rose* being most prized as containing the richest and purest juice. The Quedlinburg beet is preferred in North Germany: it is thought to keep better than the Silesian, and its juice to alter less by exposure to the air.

A section of the beet perpendicular to its axis exhibits a series of concentric rings: first there is the epidermic tissue, consisting of from 4 to 6 layers of cells, composed principally of cellulose, and containing a great part of the silica of the root: it also abounds in nitrogen. Immediately under the epidermic layer comes the herbaceous tissue, in which are principally contained the colouring principle, an essential oil, and one or two peculiar substances. The true saccharine part succeeds this: it extends to the centre, and consists of alternate layers of vascular and cellular tissue. The vascular tissue is doubled into several distinct bundles, surrounded by cells forming the whitest zones, which are most voluminous in good varieties of beet, and contain the largest amount of sugar. The leaf-stalks take root somewhat deeply in the bulb, and form what is called the *heart;* it is of a greenish colour, and abounds in fibrous vessels, containing very little sugar, but a large proportion of salts, especially nitrates. The cells sometimes contain starch, as in the early autumn.[1] The whole of the sugar in a liquid form is found in the cellular tissue, and in much greater quantity in the cylindroidal cells surrounding the fibrous tissue; the latter contains no sugar, but frequently salts in a crystalline form. Crystals of sugar also occupy a number of cells in roots where the juice is of high density, such as 12° to 14° B. The seat of the nitrogenous substance, which acts so rapidly on the juice when pressed, is supposed by Messrs. Sullivan and Gages to be in the fibrous tissue; "for when a thin slice of beet, cut perpendicular to the axis, is exposed to warm air, the concentric rings of the vascular tissue first become black." The whole of the sugar in the beet is crystallizable cane-sugar; neither grape sugar nor mannite exists in the beet, unless it has undergone some change. The per-centage of sugar gradually increases until the beet is fully ripe, and it has been shown that by good cultivation the amount of sugar which the beet may contain is nearly equal to that of the sugar-cane. As soon as the flower-stalk begins to form, the per-centage of sugar declines, and when the seed is formed it is reduced to almost nothing.

The composition of the beet-root is very complex. It contains on an average 10 per cent. of sugar, 3 of pectine, soluble salts, &c., and 83 per cent. of water; thus making 96 of juice, the remaining 4 parts consisting of albumen, woody fibre, and insoluble salts.

The following is the analysis of some beet-root grown at Giessen, first in the fresh state, and then after having been dried:—

	Fresh.	Dry.
Albuminous matter	2·04	11·5
Sugar	12·26	68·8
Cellulose and other nitrogenous substances	2·56	14·6
Mineral substances	0·89	5·0
Water	82·25	—
	100·00	99 9

The juice of the beet-root ferments like that of the sugar-cane: it generally undergoes the mucilaginous fermentation: mannite is produced at the expense of sugar, and a kind of mucus is formed which is precipitated by alcohol, and resembles gum-arabic in appearance and composition.

M. Payen gives the following as the results of his examination of the beet:—

Water	83·5
Sugar	10·5
Cellulose	0·8
Albumen, caseine and other nitrogenous substances	1·5
Malic acid, gummy substance, fatty substance, aromatic and colouring principles, essential oil, chlorophyle, asparamide; oxalate and phosphate of lime, phosphate of magnesia, muriate of ammonia; silicate, nitrate, sulphate and oxalate of potash; oxalate of soda; chloride of sodium and of potassium; pectates and pectinates of lime, of potash, and of soda; sulphur, silica, oxide of iron, &c	3·7
	100·0

It has been shown by practical experiment and chemical analysis, that there is no material difference in beet grown over a region extending from the Atlantic Ocean to the Caspian Sea, and from the Mediterranean Sea nearly to the Arctic Ocean.

Beet will grow upon all kinds of soil; but a light rich loam, rather inclining to clayey than to sandy, is best adapted to produce abundant crops of good quality. The soil must be well worked and to a considerable depth, that the bulb may have room to expand, and not have to throw out too many roots in search of food. Rich nitrogenous manure, such as farm-yard manure, guano, &c. should not be applied to the land immediately before sowing; but should be applied with the previous crop or during the preceding autumn, or be put on as a winter compost.

(1) This fact appears to have been first ascertained by Messrs. Sullivan & Gages, and is stated in their "Report on the composition of White Silesian Beet grown in Ireland, in 1851, considered in reference to its employment for the Manufacture of Beet Sugar." This Report forms an Appendix to Sir Robert Kane's "Report of Inquiry into the Composition and Cultivation of the Sugar Beet in Ireland, and its application to the Manufacture of Sugar." Dublin, 1852.

Unless these precautions be used the juice of the beet will be rendered impure, and the proportion of readily fermenting azotised materials be increased.

Sir Robert Kane, in the official Report already referred to, thus refers to the proposal to introduce the manufacture of beet-root sugar into Ireland:—"It is certain that by no process as yet employed are the manufacturers able to extract absolutely all the sugar really contained in the beet in its crystallizable form; yet this is the object to which manufacturers should aspire, and towards which almost every day a closer approximation is made: and it is now well established that by the application of the most perfect mechanical arrangements, and the adoption of the improved chemical processes of refining, the quantity of sugar extracted in a marketable form approaches closely to that really existing in the beet, while the proportion of melasses formed is but trifling. In considering, therefore, the position of the manufacture as to Ireland, it must be assumed that the manufacture should be conducted with the most perfect means, most accurate knowledge, with careful economy, and judicious business management; for, should those conditions be not fulfilled, the manufacture would necessarily fail to succeed here, as it would fail elsewhere from the like causes; and the country or the period would be stigmatised as unsuited or improper for the manufacture, when the fault really lay with the ignorance or inattention of the individuals who had taken up an occupation for which they did not possess the necessary qualifications." The establishment of the manufacture in Ireland appears to Sir R. Kane to be "eminently calculated to be of service, not only as creating a new and extensive source of manufacturing employment, but also that as the material used can only be profitably obtained by means of improved agriculture, and that an important element in the profits of the manufacture would be the careful economy of the scums and pulp, either as manures or as food for cattle, the manufacturers of beet-root sugar should exercise a powerful influence on the agriculture of their districts, inducing a greater variety of cultivation, a more thorough preparation of the soil, and a more careful economy of manures; and that in this way, even should the manufacturing speculation become hereafter, by improvement in the management of the colonial-sugar industry, or by any other cause, less probably successful than it now appears to be, there should still have been conferred on Ireland a great advantage in the improved practice of green-crop husbandry, which would be certain to remain."

The beet-root may be kept for some months in silos, prepared in the same manner and with the same precautions as those used for keeping potatoes [see STARCH]; but there is always danger of the sugar passing into the non-crystalline variety. When the roots are about to be used, the bruised, decayed, and mouldy parts must be carefully removed, or the juice will be very liable to ferment and spoil. The leaves and the root are of course removed as soon as the plant is gathered.

The first operation in the manufacture is *washing the bulbs*, to get rid of sand and earth: this operation is usually carried on in a drum, formed of laths or bars of wood arranged parallel to a nearly horizontal axis, and partly immersed in water. On causing the drum to revolve slowly the bulbs scour each other, and the dirt passes through the open spaces. The axis of the drum is somewhat inclined, so that the bulbs being fed in at a hopper situated at the upper end of the drum pass slowly down to the lower end, where they are raised by a scoop and thrown upon a lattice frame.

The bulbs are now ready for *rasping*, the object of which is to tear open the cells in which the saccharine juice is imprisoned, and to reduce the bulbs to pulp ready for the press. The rasping or grating machine is a hollow cylinder or drum, the surface of which is thickly studded with teeth, against which the bulbs are pressed while the drum rotates; the action being very similar to the rasping machine which reduces potatoes to pulp, as shown in the steel engraving which accompanies STARCH. As in the case of that machine, a stream of water plays upon the teeth, to prevent them from becoming clogged with the pulp. The hopper is in 2 divisions, both in the same plane, and one is filled while the other is feeding the drum, which makes from 700 to 800 revolutions per minute, and reduces from 250 to 300 cwt. of bulbs into pulp daily. The drum is covered with a lid, to prevent the pulp from being thrown about, a cistern below being provided for its reception.

The third operation is the *pressing*, which is carried on simultaneously with the rasping, on account of the great tendency of the juice to spoil. The pulp is placed in bags of woollen cloth or of stout unbleached hemp of open texture, which are evenly arranged on the bed of a hydrostatic press; each bag forms a layer about 2 inches thick; the open end is turned in, and a metal plate, or a hurdle of plaited willow twigs,[1] placed upon it; another bag of pulp is then placed on, with the turned-in end in the opposite direction to the first; then another hurdle, and so on. Two presses are worked for one rasping machine, and one is emptied while the other is at work. The greater portion of the juice is expressed in about 10 minutes; another portion in another 15 minutes; while about 15 or 20 per cent. of juice remains in the pulp, a portion of which is removed by immersing the sacks in water containing $\frac{1}{1000}$th part of tannin in solution,—for the purpose of checking any tendency to fermentation, when they swell up to their former bulk,—and pressing them again; or the sacks are exposed to a jet of steam until it ceases to be condensed. Care must, however, be taken not to boil the pulp, or it cannot be pressed. The expressed juice is collected in a gutter arranged round the press, and it flows from an aperture through a pipe into a reservoir. The tables on which the bags are filled has also a gutter leading to the reservoirs, and in some factories the first pressure is made on this table, by means of a small hand-press, which expresses 30 to 40 per cent.

(1) The willow is first peeled and then boiled, in order to remove bitter and extractive matters.

of the juice; the more energetic pressure being reserved for the hydrostatic press. The rasping machine and press must be kept perfectly clean, and occasionally be washed with lime water.

The arrangement of the bags and hurdles, and the intermittent nature of the process when the hydrostatic press is employed, have led to several ingenious attempts to invent a constant and continuous press. Pecqueur's press is of this kind. It consists of a forcing-pump, which communicates the required amount of pressure to the pulp, and straining-drums, which separate it while under the influence of this pressure into juice and lees. A copper funnel opening into the barrel of the pump, is kept constantly full of pulp, so that when the piston has attained its highest position, the whole space in the barrel below it becomes filled with pulp, which is forced by the downward motion of the piston through a valve, when it is discharged into a funnel-shaped vessel of cast-iron, and communicates its pressure to the mass of pulp with which the latter is filled. This funnel-shaped vessel is closed on all sides, and the only outlet for the pulp is through two hollow perforated cylinders, surrounded by a cylinder of wire gauze: they revolve on their axis a few lines from each other, and while the juice exudes through the sides of the rollers and flows off by a pipe arranged for the purpose, the fibres are thoroughly squeezed between the rollers, and are carried upwards by the motion of the drums, and discharged at the side by means of gutters. This machine requires that the pulp be presented to it in a particular state of division, which is not always attainable, and even then it produces, by its peculiar action, much froth and scum, which are of course objectionable. Objections apply to other pressing machines; and on the whole, the hydrostatic press is the best form of press that has yet been adopted.

The objections to the above modes of rasping and pressing are, that the waste pulp or husk still contains a small proportion of sugar, and although it is good for cattle when mixed with other kinds of fodder, yet the manufacturer would prefer to obtain all the sugar from it. Besides this, the great exposure to air during the rasping and pressing blackens the juice, which has been already reddened by the nitrogenous substances present, thus leading to the decomposition and destruction of a portion of the sugar. The presses also discharge into the juice not only all the soluble matters, but also the finer particles of the pulp. For these reasons, attempts have been made to obtain the juice by the process of *maceration*, which has been conducted in a variety of ways; but the essential steps are to cut the bulbs into thin slices, and digest them repeatedly in warm water. According to one plan, the slices are suspended in baskets, with an equal weight of water at 167°, and allowed to digest for half-an-hour; a liquor is thus obtained marking 4° on Baumé's aerometer; the slices are taken out and fresh slices added, and the liquor attains the density of 6° B.; a third set of slices raises it to 7° B., and it is now fit for working. The slices of beet that have once been used are repeatedly macerated in water, and the liquor is used with fresh slices instead of pure water. Various other ingenious plans of maceration have been contrived, and carried on for some time and then abandoned, the great objection being the large quantity of water thus introduced into the juice, which has afterwards to be removed by evaporation.

For some years past attempts have been made to dry the beet-root as soon as it is harvested, so as to diminish its bulk about 84 per cent., leaving only 16 of dry matter; it could thus be transported to very great distances; the beet-root sugar factories could be worked during the whole of the year; and a rich pure juice be obtained ready for the clarifier immediately. The expense of fuel is the great objection to the process, but the following plan is said to have been adopted with some success. The beet-roots having been pulled are washed, and then by means of a turnip-cutting machine, cut up into small cubes or parallelopipeds, which are dried upon floors similar to those used for drying malt. [See BEER, Fig. 106.] In order to extract the sugar from these dried fragments, or *cossettes*, as they are named in France, they are placed with 5 parts per 1,000 of their weight of hydrate of lime, in large cylinders of sheet-iron encased in wood to prevent loss of heat. The cylinders are charged by a manhole in the upper part of each, which can be closed at will. There is also a pipe for introducing water and a pipe for extracting the air by means of an air-pump. At the lower part of each cylinder is a false perforated bottom, and below this a pipe, which also passes into the upper part of the next cylinder below. The cylinders being charged with cossettes, water from an upper reservoir at the boiling temperature is allowed to flow upon the cossettes. After macerating for some minutes, the liquor is passed from the first into the second vessel; from the second into the third, and so on to the fourteenth. In this way the syrup in passing from one vessel to another, increases in saccharine value, and the last maceration is upon fresh cossettes. The resulting syrup is of the density of 22° B. It is drawn off and mixed with a portion of the liquor of the preceding vessel, which takes its place until its density is 17°: it is then heated to the boiling point, passed through the charcoal filters and then into the vacuum-pan. The complete apparatus which furnishes the syrup consists not of 14 vessels as above indicated, but of 20; 14, however, are only in actual use at one time, 4 being in course of emptying, cleaning, and recharging, and 2 being left charged in case of repairs being wanted in those actually in use. A syrup produced by the action of cold water is said to give a juice more readily worked for crystalline sugar than when hot water is employed.[1]

However the beet-root juice is obtained, it must be raised almost as soon as obtained to the temperature of 140° and upwards, to preserve it from fermentation.

(1) There is an extensive factory of beet-root sugar on the above plan at Waghäusel, near Heidelberg. An English Beet Sugar Company is about to adopt the plan in this country.

The defecation is conducted by means of hydrate of lime, the quantity of which varies with that of the acids to be neutralized, from 3 to 6, 8 and 10 kilogrammes of lime to 1000 litres of juice. The heating and defecation are conducted in such a vessel as Fig. 2099. To obtain a clear liquor an excess of lime must be used, which was formerly saturated with dilute sulphuric acid; but as this transforms the crystallizable sugar into glucose, which is more injurious than the lime, the use of alum has been introduced; whereby sulphate of lime is formed, and the alumina, set at liberty, assists the clarification. Ammonia alum, not potash-alum must be used. It has been proposed to employ in the clarification pectic acid, which has no injurious action on the sugar. The filtration is conducted in beds similar to those shown in Fig. 2101, and the filtered liquor is rapidly evaporated to 25° B., in vessels similar to Fig. 2103; then filtered again, and passed into the vacuum-pan.

In addition to Fig. 2103, there are various forms of evaporators in use. That shown in Fig. 2115, called "the evaporating cone of Lembeck," used by M. Claes, of Lembeck, near Brussels, is said to be effective. It consists of a double conical envelop, C C, about 16 feet high, heated by steam of the pressure of 4 or 5 atmospheres. The interior of this hollow cone receives the syrup from a reservoir S, which is furnished with a ball-cock *c f*, for the purpose of keeping

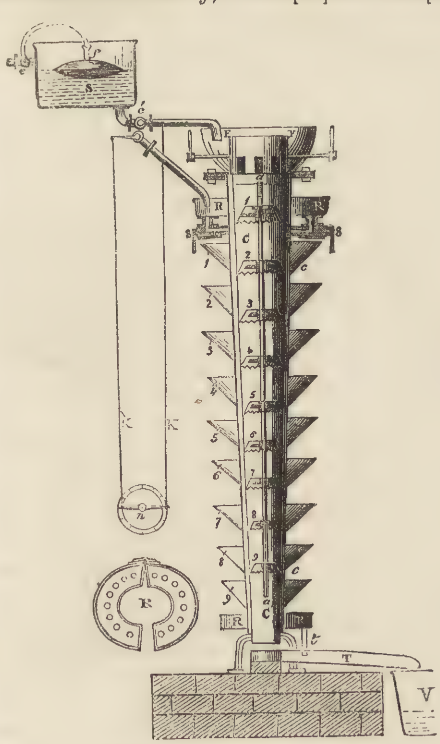


Fig. 2115. EVAPORATING CONE.

the level constant. The syrup flows from the stop-cock *c′* into the funnel F, whence it is distributed by 6 or 8 openings over the interior surface of the cone. The liquid in descending is divided and distributed by means of 9 hollow conical segments, 1 .... 9 toothed at the lower edge, and attached to an axis or stem *a a*, by which they may all be withdrawn from the interior of the large cone when the apparatus requires cleaning. The exterior surface of the large cone also receives a layer of the syrup to be evaporated, which is supplied to it from the cistern S by a cock R, which feeds the funnel R R, and from this funnel proceed 16 channels in the form of right angles, their openings being within a few lines of the outer heated surface of the great cone. The liquid in descending meets the hollow conical vessels 1′.... 9′, also toothed at the lower edge for the purpose of redistributing the liquor round the cone. At the bottom of the cone the liquor falls into an annular reservoir R′, (the plan of which is shown in the separate figure R,) whence it passes by the small channels *t* along the trough T into a cistern V. By placing a second trough parallel with T, the liquor from the interior and the exterior of the large cone may be received into separate vessels and the evaporative effect noted. If the concentration be not satisfactory, the rate of efflux of the syrup may be regulated by means of the cords K K′, one of which acts upon the cock which supplies the interior of the cone, and the other upon that which supplies the exterior: the ends of the cords are attached to the points of a needle *n* moving on a dial, which indicates the rate of discharge. Evaporating cones of this kind frequently take the place of vacuum-pans.

There are various kinds of tests to which syrups are subjected, for ascertaining when they are fit for the purpose intended. They are at best but workman's tests, but seem to answer the required end. The first (which has been already referred to in Sect. II.) is called the *string-test*, or *preuve au filet*, and consists in taking a drop of syrup between the finger and thumb, and suddenly removing them from each other: if the syrup admit of being drawn out into an attenuated thread, it is sufficiently concentrated for the required purpose. If the thread breaks and forms in curling up a little hook, the evaporation is said to have been carried to the *preuve au crochet*. There are, however, two kinds of crochet, the *weak* and the *strong*. For candies the *preuve au soufflé*, or *bubble test*, is attained in open boilers, in which, on dipping a skimmer into the syrup, holding it up vertically and blowing forcibly through the holes, bubbles of syrup are formed on the other side: if a large number of bubbles are detached in the blowing, the proof is said to be *soufflé fort:* if only a few bubbles are detached, the proof is then termed *soufflé leger*. In the manufacture of barley-sugar and other sweetmeats, there are proofs termed *le petit cassé*, *le grand cassé*, and *le cassé sur le doigt*. The first of these three is when the finger is moistened, dipped into the syrup, then into cold water, and thus prepared the sugar can be rolled into a ball, which, on being thrown upon the ground, splits and loses its shape. In the second kind of proof the ball thus formed is sufficiently hard and brittle to fly to pieces when thrown on the ground. In the third kind of

proof the sugar solidifies on the finger into a brittle envelope.

M. Payen has in the following table given precision to the above tests, by assigning to them their respective temperatures, and the proportions of sugar and water in 100 parts of the sugar at each test:—

Tests.	Temperature. Cent.	Fahr.	100 parts contain Sugar.	Water.
Filet	109°	= 228·2° ...	85	15
Crochet leger	110·5°	= 230·9 ...	87	13
" fort	112	= 233·6 ...	88	12
Soufflé leger............	116	= 240·8 ...	90	10
" fort	121	= 249·8 ...	92	8
Cassé petit............	122	= 251·6 ...	92·67	7·33
" grand	128·5	= 263·3 ...	95·75	4·25
" sur le doigt...	132·5	= 270·5 ...	96·55	3·45

If the defecation and clarification of the syrup have not been well conducted, or if the proportion of lime has been too small, the syrup is liable to froth and foam up a good deal in the boiling. This is corrected by throwing into the syrup a piece of butter, which, in melting, spreads over the surface, lubricates the bubbles, and enables them to glide over each other and break, whereby they are prevented from foaming over the sides of the boiler. An excess of lime produces a contrary effect, especially if the beet-root contain much oxalate of potash: the syrup will not boil; an increase of heat deteriorates the liquor by converting the sugar into caramel, and it is extremely difficult to bring it to the point of crystallization. In such a case the syrup must be filtered through fresh animal charcoal, or be mixed with syrups containing a little saccharate of lime or of potash.

The boiling is continued for 10 or 12 minutes, and when the syrup answers to the desired test it is drawn off into coolers or heaters, as the case may be, and then poured into moulds, as described in Section III. The centrifugal machine, Fig. 2114, is also used by many manufacturers of beet-root sugar.

The attempts to diminish the cost of production of beet-root sugar have led to the invention of a number of ingenious processes, most of which, although not successful in practice, are nevertheless worthy of study as examples of manufacturing chemistry. Our space, however, will not allow us to notice more than one or two. The following process is based on the chemical fact, that when sugar unites with lime its properties undergo no change, and it may be recovered with little or no loss. Now it was proposed in 1838 by M. Kulhmann, to employ an excess of lime so as to convert all the sugar into saccharate of lime, and after having undergone the processes of defecation and evaporation to recover the sugar by saturating the lime with carbonic acid. The proposed advantages were the protection of the juice from all deteriorating influences and the saving of animal charcoal, for it was supposed that filtration would not be necessary. This plan has lately been perfected in France, and the following is a brief outline of it. The juice is prepared in the usual way up to the point of defecation, which process is conducted in a vessel similar to that represented in Fig. 2099 heated by a steam-jacket; but instead of the usual dose of lime being used, six times that quantity is added to the juice, sufficient not only to act on the acids and other substances, but also to form a saccharate of lime (containing 2 equivalents of sugar and 3 of lime) with the whole of the sugar in the juice. About 25 kilogrs. of lime are required for 1,000 litres of juice: the lime is slacked with 5 or 6 times its weight of water, and mixed with the juice, which is heated to from 140° to 150° Fahr.: the whole is then raised to about 203°, but is not allowed to boil. The liquor is next decanted and passed through a layer of animal charcoal 10 inches thick, resting on a filtering cloth on the perforated false bottom of a shallow vessel: the juice is limpid but slightly yellow; it is passed into a second copper heated by a steam-jacket, and here the lime is saturated with carbonic acid, and the sugar set free. The carbonic acid is generated by means of a blast of air driven by a small blowing machine into a small close furnace full of incandescent coke and charcoal. The oxygen of the air in passing through the burning fuel is converted into carbonic acid, and this, with the nitrogen, is driven forward by the blowing machine, first into a close vessel containing water where the gases are washed, and then by a pipe from the top of the washing vessel into the solution of saccharate of lime, where it is delivered by a rose-head, which divides the gas into numerous small bubbles. The carbonic acid gas combines with the lime, producing an abundant precipitate of carbonate of lime. When the saturation is complete the supply of gas is cut off; the liquor is raised to the boiling point to expel the excess of gas, and it is next passed into an ordinary filter of animal black. The proceedings are afterwards of the usual kind. M. Payen, who has personally examined the above process in actual operation, recommends it as greatly facilitating the operations of the manufacturer: it produces no pan-scratch in the evaporating vessels; the juice, which is purer than by the ordinary method, never foams up in boiling, and consequently requires no consumption of butter; the quantity of animal black required for the filters is only $\frac{4}{10}$ths the usual quantity; the crude products have an improved taste, and the crystallized sugar obtained every day is equal to sugar refined in the usual manner. M. Payen recommends that the carbonic acid be generated by the combustion of a mixture of coke and chalk, as is done in the process for manufacturing *Clichy white.* [See LEAD, Fig. 1276.]

The secondary products of the beet-root are very different from those of the sugar-cane. The pulp which is left after the expression of the juice is an excellent food for sheep and cattle. Its composition varies with the kind of beet employed, and the manufacturing processes for extracting the sugar. In some parts of the continent it is far more valuable than the raw beet. The experiments and analyses of Dr. Sullivan, as stated in the Report already referred to, led him to the remarkable result, "that pulp is as nearly as possible of the same value as raw beet, one constituent merely replacing another. In the raw beet the sugar forms the preponderating constituent belonging to the class of non-nitrogenous substances capable of being assimilated by animals: in the pulp, a consi-

derable part of the sugar is replaced by pectine, which fills the same office as food."

The melasses from raw cane-sugar is also essentially distinct from the melasses of the beet-root; the latter consisting of the mother liquor more completely exhausted, with less sugar and more foreign ingredients. They contain, however, all the non-crystalline sugar to which the cane-sugar of the beet has been degraded, and other organic matters of the juice, together with saline matter, gum, or mucus, to which beet-root melasses owe their nauseous taste. They are occasionally mixed with the refuse pulp and given to cattle, and are also used for the production of alcohol: they contain about half their weight of solid sugar, and yield about 30 per cent. of their weight of alcohol. The residue after distillation is dried and calcined, and leaves about 10 or 12 per cent. of the weight of the melasses in the form of a saline mass, rich in alkali, containing from 7 to 11 per cent. of sulphate of potash; 17 to 20 per cent. of carbonate of potash, 27 to 45 per cent. of chloride of potassium, 25 to 34 per cent. of carbonate of soda, and traces of cyanide of potassium. Thus the production of potash may be connected with the distillation of melasses for alcohol, the residue being used for diluting fresh portions of melasses. In factories where the daily consumption of beet is about 600 cwt., about 5 or 6 cwt. of mineral ingredients, and 3 to 4 cwt. of this saline mixture are produced. When the calcined saline mass is purified by solution, a double salt crystallizes $=KaO,CO_2+NaO,CO_2+12aq.$, which can be converted by means of carbonic acid into carbonate of potash and bicarbonate of soda.

The scum which is removed during the process of defecation, and the residue left in the filters after the separation of the filtered juice, together with the waste of the bone-black employed in the filters, form a valuable manure. The scum consists of an excess of lime, phosphate of lime, and magnesia separated from the juice; a great part of the nitrogenous substances found therein; organic acids in combination with lime, &c.

Section VI.—Manufacture of Maple Sugar, etc.

Several species of maple contain a sweet juice in their stems of the sp. gr. 1·003 to 1·006, which, on being evaporated, yields a syrup containing cane-sugar. The *Acer saccharinum* is most abundant in juice. In the United States and Canada the maple forms large forests, and the manufacture of sugar from its juice is a regular branch of industry. It is necessary, however, frequently to change its locality, since the operation of tapping the tree for its juice is injurious to its economy. The tools consist of a few large awls or borers, wooden pipes of the size of the awls for drawing off the juice, and troughs for collecting it; boiling-pans of the capacity of 13 to 15 gallons; casks, moulds, and axes for clearing wood for fuel. The juice is collected in February and early in March, when the sap is most abundant. Two holes are bored on the south side of the tree, 4 or 5 inches apart, and 18 or 20 inches from the ground: they are made to slope upwards, and do not penetrate more than half an inch into the white bark or splint of the stem, which yields the largest quantity of juice. The juice is collected during about 6 weeks, at the end of which time it becomes more impure, and contains less sugar. From the troughs it is removed by cans into a hut, and poured into reservoirs which supply the boilers. The juice cannot be kept for more than 2 or 3 days, according to the temperature, without fermenting. The boilers are heated by a brisk fire, and the scum is removed as fast as it forms, and fresh juice is added as the bulk diminishes by evaporation. The syrup, when properly concentrated, is strained through a woollen cloth, then boiled quickly down in another pan, cooled, and poured into moulds to crystallize. When the syrup has drained off, the remaining sugar is dry in the grain, of pure taste, and equal to raw colonial sugar. The maple juice is much more free from foreign matters than that of the beet. The proportion of sugar in the juice of the maple has been variously stated; but it probably does not contain more than one half the sugar contained in the juice of the beet.

The stems of Indian corn also contain sugar, and attempts have been made to manufacture it. It has been stated that 8,700 stems yield 7,131 lbs. of juice, from which 35 lbs. of crystallized sugar and 70 lbs. of syrup are obtained. The quantity of sugar in the stems varies in different countries, and the economy of the manufacture does not appear to have been well ascertained.

The common gourd, *Cucurbita pepo*, has been used in Hungary for the manufacture of sugar: the gourds are said to contain 82 per cent. of juice, of 10° to 11° B., and to yield a species of raw sugar moderately coloured, and having the taste of melon: but by refining it yields sugar equal to that of the cane.

The various kinds of palms also contain in their stems a juice charged with cane-sugar, which, in the fresh state, is named *toddy*, in India, and when fermented and distilled, *arrack:* it is by the evaporation of toddy that the sugar termed *jagery* is obtained. The process is noticed under Coco-nut Tree. The Ryots, or poor peasants dependent on the land-owners in the East Indies, also cultivate the sugar-cane, express the juice, and boil it down to a thick syrup: they then transfer it to the Goldars, who produce the solid sugar. The crude syrup is named *goor*, and is of various qualities, one of which, in common use, is also called by the English settlers *jagery.* There is an association of farmers, who convert the syrup and send the produce of each man's land to a common manufactory. Jagery is sometimes adulterated with earth and sand. The French colonists of Pondicherry prepare refined sugar from jagery: it is of a yellowish white colour: it is known in the English market under the name of *date sugar.* A similar product from Africa is known as *date-sugar of Mogador* (the port of Morocco).

Chestnuts, the fruit of the *Cactus opuntia*, and a species of wild daffodil (*Asphodelus*), have all been proposed as sources of sugar.

Section VII.—Manufacture of Rum.

The refuse of the sugar-cane is chiefly employed in the manufacture of rum. The melasses, the skimmings from the clarifying and evaporating coppers, and even raw cane-juice diluted with water, are all used for this purpose; *dunder*, or the wash of former operations, deprived of its alcohol by distillation, being used as a ferment. The fermentation is complete in from 5 to 7 days, and the liquor must be transferred to the still before the acetous fermentation shall have set in. A small portion of lime or of solid limestone is added to correct any acidity that may have formed. The spirit is allowed to flow through the worm until it is no longer inflammable. It is then rectified in a smaller still. [See Distillation.] Mr. Wray[1] states that 1,200 gallons of wash yield 113 gallons of proof rum. Rum is coloured by means of caramel.

Mr. Wray lays great stress on the action of the dunder. He terms it the aromatic substance which modifies the changes or transformations which take place during fermentation: that it increases the density of the liquor, and prevents violent fermentation; that good dunder should be light, clear, slightly bitter, and quite free from acidity; and that its action is similar to hops in diminishing the influence of decomposing azotised bodies, which is to convert alcohol into acetic acid.

Messrs. Pontifex & Wood, who have done so much for the improvement of the sugar apparatus of our colonies, have also brought out a still for facilitating the production of rum. They have lately patented a continuous distilling apparatus, for obtaining a spirit of any required strength by a single distillation. This object is attained by certain arrangements based on the well-known principle [see Distillation] that spirit will remain in a state of vapour at a much lower temperature than water. If, then, the vapour which rises from the wash, and which contains both spirit and water, can be reduced in temperature, the former only will remain vaporized whilst the latter will be condensed, a strong spirit being thus at once obtained.

The agent used for reducing the temperature of the mixed vapours is the cold wash itself, which, commencing at the point whence the vapour is about to pass into the worm, gradually traverses the different parts of the apparatus, assimilating to itself the waste heat from the vapours, which is usually lost, until it arrives at the body of the still, by which time, in consequence of its having been all along in contact with the hot rising vapour, it has been completely robbed of the whole of its spirit, and is therefore at once run off through a waste pipe. The hot vapour, in its gradual ascent, meets with the descending stream of cold wash, from which it withdraws the spirit, and by which it is sufficiently reduced in temperature to free it from the watery particles. The steam rising from the body of the still A, Fig. 2116, is first met by the descending column of cold wash in the rectifier C; as much of the vapour of water as is required to be separated is there condensed by regulating the supply of cold wash and so raising or lowering the temperature as required, the spirituous vapour passing over into the worm tub D. In the analyzer B the wash, which has already robbed the

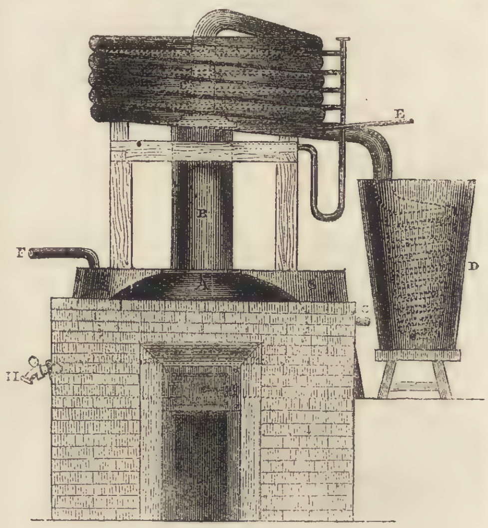


Fig. 2116.

vapour of its watery particles, is in its turn robbed by the vapour of its spirit, which, with some vapour of water mixed with it, passes over into the rectifier to have the latter separated by fresh portions of cold wash. The wash-pipe is shown at E.

The separation of the vapour of spirit from the vapour of water is effected in the analyzer by a very peculiar arrangement, the stream of wash being made to fall in a shower of minutely divided particles, through the midst of which the mixed vapour is rising, and which is thereby much reduced in temperature, causing the watery particles to separate and fall back into the still, whilst the hot vapour continues its onward course, taking with it the spirit from the wash. The supply of cold wash being constant, and the waste wash from the still always running off at G, the continuous action of the still is effected, and the time usually lost in charging and discharging is thereby saved.

The peculiarity of this arrangement is, that the still itself merely supplies the heat which is to effect the distillation, that being in fact completed before the wash reaches the body of the still, and its advantages are an immense saving of time, fuel, and labour, considerably lessening the cost of the apparatus, and rendering it much less cumbersome.

It will be seen from Fig. 2116 that this still may be adapted either to work by fire or by steam. If by steam, the body of the still A, which may be made either of copper or of wood, will be represented by the square box S′ S′, with F for the steam-pipe. If by fire, the body A is of the ordinary form, in which H is the discharge-cock.[2]

(1) "The Practical Sugar Planter," by Leonard Wray. 8vo. London, 1848.

(2) Messrs. Pontifex & Wood, to whom we are indebted for information in the preparation of this article, have furnished us with a few notes on the last sheet (p. 769 to p. 784), which they did

Section VIII.—Statistics of Sugar.

The production of sugar in the year 1850 has been stated in the *Economist* as follows:—

I. Free Labour.

	tons.	tons
British possessions	260,000	260,000
FOREIGN FREE LABOUR.		
Java	90,000	
Manilla, Siam, and China	30,000	
United States, maple sugar	70,000	
French West Indies and Bourbon	60,000	
Europe beet-root	190,000	
		440,000
Total free-labour sugar		700,000

II. Slave Labour.

Cuba	250,000	
Porto Rico	46,000	
Brazil	110,000	
Dutch West Indies	13,000	
Danish	8,000	
Louisiana	124,000	
		551,000
Grand total		1,251,000

The consumption of sugar per head in the following countries has been thus estimated:—

	lbs.
In the countries of the German League	4·08
France	6·5
Spain	3·5
Holland	14·5
Belgium	7·0
Russia	0·5
Ireland	4·5
England and Scotland	21·0
The United States	14·5
Cuba	56·0
Venezuela	100·0

not see until after it had gone to press. It is stated on page 774, that the Batavian cane is cultivated in Java chiefly for the manufacture of rum; whereas no rum is manufactured in Java at the present time. With respect to the mills, such as Fig. 2094, the main improvements consist in a better and more scientific distribution of the strength of material, and the moderate speed at which the rollers are driven. At page 777 is noticed a proposal to dip the crushed canes into water, and pass them a second time through the mill. In addition to the objections stated in the text, it has been remarked to us that by this plan the organic acids, &c. would be so largely extracted as to produce more injury to the juice than would be compensated by the increased quantity of sugar. In the process of defecation, p. 778, we are informed that an important improvement is about to be brought out, which will admit of any quantity of lime being used, from which the sugar may afterwards be separated by very simple means. We have already referred to a plan of this kind, p. 794, in which carbonic acid is used for separating the sugar from the lime; but the plan in question is said to be much simpler. Messrs. Pontifex & Wood state that the method of concentrating the juice for the vacuum-pan, p. 781, and Fig. 2104, was patented by them in England, and by M. Derosne in France. Respecting the use of butter or grease in the vacuum-pan, p. 783, when it is required it is a proof that the operation has been badly conducted, and that incipient fermentation is causing undue ebullition. In the same page it is stated that proof-sugar boils at 145° in the vacuum-pan, when the pressure is 3 inches *above* a perfect vacuum. The word *above* should be *below*. If the mercurial column were acted on by the pressure of the vapour within the pan, and that were capable of supporting 3 inches of mercury, then the expression 3 inches *above* a perfect vacuum would be correct; but as the barometer-tube opens into the vacuum-pan, and the mercury is supported in it by atmospheric pressure, then 3 inches below a perfect vacuum would be a height of mercury equivalent to 27 inches,—30 inches marking a perfect vacuum, as in the case of the gage attached to the air-pump, *d*, Fig. 20. [See Air.] In p. 784 the sugar is stirred in the heater to *promote* not to *prevent* granulation.

The reader who desires a fuller notice of this important manufacture, will do well to consult the third volume of the English translation of Knapp's Technology: the sixth volume of Dumas' "Traité de Chimie appliquée aux Arts," and Payen's "Chimie Industrielle" 1851.

The quantity of sugar imported into the United Kingdom in the years 1851 and 1852, was as follows:—

From	1851.		1852.	
	Unrefined.	Refined, and Sugar Candy.	Unrefined.	Refined, and Sugar Candy.
	cwt.	cwt.	cwt.	cwt.
British West Indies and Guiana	3,064,793	60	3,398,760	667
Mauritius	999,237	28	1,121,996	1,111
British East Indies	1,565,878	31,400	1,301,982	2,541
Ceylon	4,874	2	1,667	...
Singapore	81	...	...	...
Other parts	1,367	...	9,495	35
	5,636,230	31,490	5,833,900	4,354
Foreign countries	2,296,304	417,051	1,068,564	299,511

The total amount of sugar from British possessions entered for home consumption was, in the year ending 5th Jan. 1852, 4,890,430 cwts; the amount of duty received 2,550,148*l.* Of the foreign sugar, 1,681,196 cwts. were entered for home consumption: the amount of duty received was, 1,428,992*l.*

Melasses—	1851.		1852.
	cwts.		cwts.
From British West Indies and Guiana	492,056	...	472,933
,, Mauritius	740	...	—
,, British East Indies	9,848	...	5,580
Of foreign produce	2,621	...	420
Total	505,265		478,933

Rum—			
	gallons.		gallons.
From British West Indies and Guiana	4,176,137	...	5,058,023
,, Mauritius	21,442	...	8,097
,, British East Indies	414,818	...	307,382
,, Ceylon	35,347	...	21
Total	4,647,744		5,373,523

After the 5th July, 1854, the duties on foreign and colonial sugar, then to be equalized, will be on refined sugar, 13*s.* 4*d.* per cwt.; on white clayed, 11*s.* 8*d.*; on brown, 10*s.*; and on melasses, 3*s.* 9*d.*

The average price of West India brown sugar in 1842, was 37*s.* per cwt.; in 1852 it was 24*s.* 2*d.*

A plan has been recently introduced for recovering from melasses the crystalline sugar: 3 lbs. of melasses are found to yield 1 lb. of sugar.

SUGAR OF LEAD. See Lead.

SULPHATES. See Sulphur.

SULPHUR (S.16). This important element is very abundant in nature, and occurs in greater or less quantities in minerals, animals, and plants. When united with metals it forms *sulphurets*, and when combined with metallic oxides the compounds are termed *sulphates*. Native sulphur is also found in crystals, its primitive form being an acute octohedron with rhombic base, which is the figure assumed by sulphur on separating from solution at common temperatures; but when a mass of sulphur is melted, and after partial cooling the surface-crust broken and the fluid portion poured out, it then has a different primitive form, viz. an oblique rhombic prism. Pure sulphur is a pale yellow, brittle solid, insipid and inodorous, but exhaling a peculiar odour when

heated. Its density is 1·970 to 2·080. Its specific heat 0·1880. It becomes negatively electrical by heat and by friction: it is a non-conductor of electricity, and a bad conductor of heat. If a piece of roll sulphur be ground in a dry Wedgwood-ware mortar, the powder will adhere to the mortar in consequence of the electricity developed by the friction, so that the mortar may be inverted without losing the sulphur. If a roll of sulphur be grasped in the hand, it will split to pieces with a crackling noise in consequence of the unequal expansion under a very slight heat. Sulphur may be obtained in three states. At ordinary temperatures it is solid: if it be heated to 232° and upwards it fuses into a very limpid fluid of a canary yellow colour: fragments of sulphur not melted remain at the bottom of the test-tube or vessel in which the experiment is conducted, showing that sulphur, in passing from the solid to the liquid state, increases in volume.[1] Sulphur passes suddenly from the liquid to the solid state without any intermediate viscid or sticky condition. If, when the sulphur is quite limpid and of a clear yellow colour, the temperature be raised, its colour deepens and it diminishes in fluidity. At 320° it pours with difficulty, and is of a brownish colour. At 392° it is so viscid that the mouth of the vessel containing it can be reversed and the sulphur will not escape: the colour is then of a deep brown. If the temperature be still further increased, the sulphur becomes again fluid, retaining its brown colour. At 752° it boils, and may be distilled in a glass retort over a charcoal fire. The vapour condenses in the neck of the retort in the form of a very fine powder, known as *flowers of sulphur*. If the distillation be continued until the neck of the retort exceed 232°, the temperature at which sulphur fuses, the vapour then condenses in the liquid state. In this way sulphur may be purified of foreign non-volatile substances. The vapour of sulphur is of a yellow brown colour, and of the density of 6·654, air being 1·000.

If sulphur be heated in a crucible to about 400°, and then poured in a thin stream into cold water, a brown, spongy, soft, and elastic mass is obtained, and its softness continues some time; it gradually hardens, and after some days it regains its ordinary condition of hardness, but its colour continues to be deeper than usual. But if, instead of leaving the soft sulphur to recover its hardness at the usual temperature of the air, it be heated to about 212°, it changes suddenly into hard sulphur with disengagement of heat: the soft sulphur heated to 212° rises to 230°. The soft ductile sulphur may be used for making casts and receiving impressions of seals, &c.

The temperatures at which the above remarkable series of changes take place are stated on the authority of Regnault. They differ from those which are given by Dumas as stated in the following table:—

(1) This is not the case with water; ice, which is of less density than water, in passing from the solid to the liquid state, diminishes in volume. [See ICE.]

Temperature.	Heated Sulphur.	When suddenly cooled by plunging it into water.
230°	Very liquid, and yellow	Very friable, but of the usual colour.
284°	Liquid; deep yellow	Ditto, ditto.
338°	Thick; orange yellow	Friable; the usual colour.
374°	Thicker; orange	At first soft and transparent, then friable and opaque; colour as usual.
428°	Viscid; reddish	Soft; transparent; and of an amber colour.
464° to 500°	Very viscid; brown red	Very soft; transparent; reddish.
Boiling point	Less viscid; brown red	Very soft; transparent; brown red.

Sulphur is found in large quantities in volcanic districts: it impregnates the ashes of certain extinct craters or *solfaterras*. It is also found in beds, as in Sicily, whence our chief supply is obtained; there it occurs in beds of blue clay, which occupy the central half of the south coast, and extend inwards as far as Etna. One of the excavations is said to resemble a marble-quarry, the various colours of the sulphur mingled with clay, calcareous stones and gypsum being compared to the veins in marble. The general ground colour is a rich shining grey; this is crossed by veins of sulphur of various colours, some much brighter than others. The veins most deeply coloured are nearly red and transparent, and contain what the miners call *virgin* sulphur. The fragments of sulphur, as they are got out, are collected into a heap, and melted in furnaces resembling cauldrons, 6 or 7 feet in diameter, and 4 or 5 in depth. A small opening in front of each of these is closed up with moist earth. The largest lumps of sulphur ore are arranged on a ledge fixed near the bottom of the furnace; smaller masses are next piled up, and still smaller upon these, until a sort of cupola or dome is formed; the irregular spaces are filled up with small lumps of the ore; and, lastly, the mere dust of the ore is piled up so as to form a sort of pyramid. The lower part is then covered with fine earth, arranged in a sort of conical belt 6 or 8 inches wide, for preventing the too rapid escape of the fumes after the furnace is lighted. In the course of all this piling up, care is taken to leave a small hole in the top. The fire is applied to this hole by means of a wisp of straw. The outer part of the pyramid first burns, but the fire soon gets to the interior. In about 7 or 8 hours the sulphur is extracted from the ore, and is found in a liquid state at the bottom of the furnace. The moist earth which closes the hole at the bottom is then perforated, and the liquid sulphur is received into wooden moulds of the form of a large brick. These are first moistened to prevent the sulphur from adhering, and in a quarter of an hour the sulphur-blocks can be taken out.

The earthy residues of the above operation, together with poor ores, are distilled in a rude kind of apparatus, shown in Fig. 2117. Two rows of earthen pots, *p p*, are arranged in a close furnace upon supports, so that the necks of the pots can be let into the top of the furnace, leaving the mouths free; the pots can thus be charged from without, after which the lids are cemented on, the fire is lighted, and the

distillation commences. The sulphur vapours pass over by the side tubes to the receivers *r r* on the out-

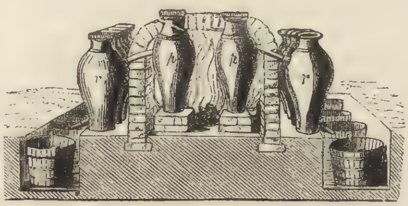


Fig. 2117.

side, where they condense into liquid sulphur, which is received in tubs of water.

For a large number of purposes the crude sulphur of commerce requires to be refined. This is done by distilling the crude sulphur and recovering it in the form of flowers, or running the melted distilled product into wooden cylindrical moulds. The furnace used for the purpose in France was contrived by M. Michel, of Marseilles, and is represented in vertical section in Fig. 2118. The distillatory vessel is a

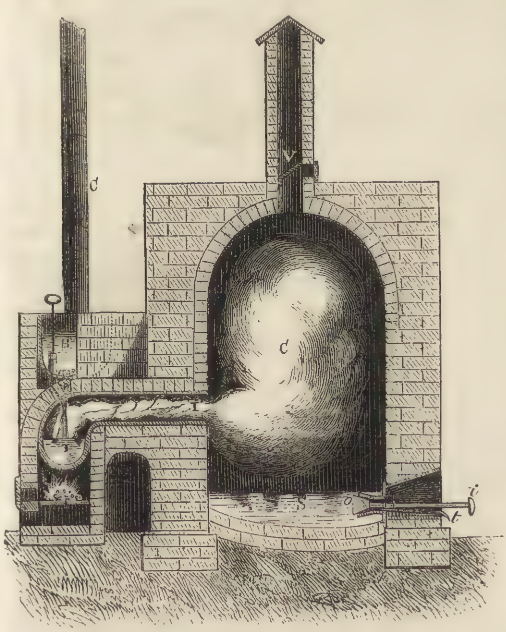


Fig. 2118. FURNACE FOR DISTILLING SULPHUR.

large cast-iron retort I I, and the cooler or receiver a spacious chamber of masonry C. The boiler or retort I is heated by a fire beneath, and it is fed by means of a second boiler B situated over it, and heated by the hot air of the flue before it escapes into the chimney C. A channel leading from the bottom of the boiler B into the retort I conducts the melted sulphur into I when the plug in B is pulled up. This contrivance allows the distillation to be carried on continuously; whereas formerly it was necessary to open a door in the side of the retort I to put in a fresh charge, and the atmospheric air coming into contact with the heated sulphur-vapour, would sometimes produce violent explosions. The preliminary fusion in the boiler B also allows the sulphur to deposit some of its impurities before it is let down into I. The vapour of sulphur raised in the vessel I passes along its neck into the chamber C, where it condenses under the form of flowers of sulphur. The hot air of the chamber may be allowed to escape by the valve V; and if it be desired to have the sulphur only in the form of flowers, the chamber must be of large size, and be kept below 232°, and the operation be conducted slowly, and interrupted often, so as to keep the chamber below that point. The flowers are removed when the chamber is cold, by a side-door provided for the purpose. If liquid sulphur is required for casting into rolls, the chamber must be smaller, and the operation conducted without interruption: the temperature of the chamber soon rises above the fusing point of sulphur, which accumulates in the bed of the chamber S, from which it may be drawn off by the gutter *t* on loosening the plug *o* by means of the handle *i*. The moulds are of deal, slightly conical, and moistened to prevent the sulphur from adhering. The lower end of each mould is plugged before the melted sulphur is poured in; the sulphur crystallizes first at the sides of the mould, and afterwards at the axis; it contracts on cooling, so that the rolls are easily removed from the moulds.

Some remarks respecting the commercial importance of sulphur will be found in our INTRODUCTORY ESSAY, p. cii. In the year ending 5th January, 1852, the quantity of *brimstone*[1] imported into the United Kingdom amounted to 768,299 cwts.

The most important compounds of sulphur and oxygen are *sulphurous acid*, SO_2. and *sulphuric acid* SO_3. The former is produced when sulphur is burnt in dry air or oxygen gas. It may also be prepared by heating sulphuric acid with mercury or clippings of copper; part of the acid undergoes decomposition, one-third of its oxygen being taken up by the metal, and the sulphuric acid becomes converted into the sulphurous. Sulphurous acid is a colourless gas, with the suffocating odour of burning brimstone; it extinguishes flame and is irrespirable. Its density is 2·21, and 100 cubic inches weigh 68·69 grains. At the zero of Fahrenheit's scale sulphurous acid condenses into a limpid colourless liquid. Cold water dissolves more than 30 times its volume of sulphurous acid. If the solution be exposed to air, the oxygen gradually converts the sulphurous into sulphuric acid. Sulphurous acid, or the fumes of burning sulphur, is sometimes used for fumigating apartments for the purpose of destroying insects. This gas may also be used for extinguishing the burning soot of a chimney on fire, for which purpose a handful of sulphur thrown into the grate may be sufficient. Access of air to the fire ought, however, to be excluded by means of a damp cloth. Sulphurous acid has bleaching properties, and is used for whitening woollen goods, silk, isinglass, sponge, and the straw used in the straw-hat manufacture. The articles to be bleached are hung

(1) From the Saxon *brenne-stone*, or burning stone.

in a damp state on strings across a close chamber, in the corners of which pots of burning sulphur are placed; all the openings are stopped with wet clay during the *sulphuring*, except one hole for admitting a limited supply of air, and another for the escape of the used gases. Of late years, however, an aqueous solution of sulphurous acid, or sulphite of soda or of potash in solution, has been used as a far more convenient method of applying the bleaching properties of sulphurous acid. Fruit stains may be removed from linen in this way. Sulphurous acid is also used for altering the colour of hops, for modifying fermentation in wine-vats, and for fumigating casks in which fermented liquors are to be kept in order to prevent acetous fermentation.

Sulphuric acid. SO_3. The discovery of this important compound is one of the numerous obligations which we have received from the alchemists. As heat of varying intensity was the grand agent of those remarkable men, they applied it in various ways to the different substances with which they were acquainted. Thus Basil Valentine, a monk of Erfurth in Saxony, about the year 1440, distilled a quantity of green *vitriol*,[1] or sulphate of iron, in a retort at a red heat, and he obtained an oily, smooth-pouring liquid, which he named *oil of vitriol.* The solid brown-red substance left in the retort was called *caput mortuum vitrioli.*[2] He also discovered that the acid vapour produced by the combustion of sulphur in the air may be collected in a liquid form by burning the sulphur in a crucible under a bell-glass, moistened with water, and suspended so as nearly to touch the dish containing the crucible. After some hours, a small quantity of acid was produced, which was named *oil of sulphur per campanum*, or *by the bell.* The solution was made stronger by boiling it in a glass vessel. To Valentine are we also indebted for the germ of the modern process of producing sulphuric acid. In a curious work, entitled "The Chariot of Antimony," he states that *oil of antimony* may be made by burning equal parts of sulphur, sulphuret of antimony and nitre under a bell-glass. In the modern process of manufacture nitre is mixed with the burning sulphur, for the purpose of enabling it to receive its highest degree of acidification.

Sulphuric acid continued to be a costly article until comparatively recent times. The oil of sulphur per campanum was long sold at the rate of 2*s.* 6*d.* per oz., and the common oil of vitriol from the sulphate of iron at about the same sum per lb., and it was regarded as an important improvement, when Homberg was able to produce 5 oz. of oil of sulphur in 24 hours.

About the year 1740 a proposal was made still further to increase the product: it was suggested by two French chemists, that as nitre contains 48 per cent. of oxygen, it might be mixed with sulphur, and the combustion be carried on in close vessels. It was thought that the quantity of oil of sulphur would thus be increased, which really is the case, even when the nitre is far too small in quantity to supply the oxygen required; for it acts in a different manner, as will be explained hereafter. Dr. Ward adopted the suggestion, and took out a patent for the manufacture. He erected his apparatus at Twickenham, and afterwards at Richmond, near London. He used large glass receivers containing a few pounds of water, and arranged in a sand-bath with the necks projecting, as shown in Fig. 2119. A small stoneware pot was placed in each receiver, supporting a shallow dish, into which a ladleful of sulphur mixed with $\frac{1}{8}$th its weight of nitre was introduced. This being kindled by a hot iron, the necks of the receivers were closed with wooden stoppers. Combustion went on for some time, and the water absorbed the acid vapours. The air in each receiver was then renewed, and a fresh charge introduced. This was done several times, until the water became highly acidulated. It was then drawn off, and concentrated by boiling in glass retorts. A strong acid was thus produced, and sold at what was then the low rate of from 1*s.* 6*d.* to 2*s.* 6*d.* per lb. It was called *oil of vitriol by the bell*, in order that people might suppose it was formed by the combustion of sulphur under a bell-glass as already described.

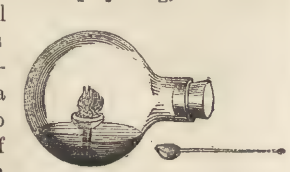


Fig. 2119.

The use of these large glass receivers was both expensive and dangerous, and served to keep up the price of the acid. Dr. Roebuck, of Birmingham, suggested the use of lead vessels instead of glass, and thus arose the present method of manufacture. The first leaden chamber was erected about the year 1746; but the expense and risk of land carriage (the only means of conveyance at that time) caused the product of the manufacture for some time to be chiefly confined to Birmingham and its neighbourhood. When this acid superseded the use of sour milk in bleaching, sulphuric acid works were established at Preston Pans, on the eastern coast of Scotland. In a few years Messrs. Roebuck and Garbett supplied the home demand at a reduced rate, and exported large quantities to the continent. In 1756 one of their workmen went to Bridgenorth, his native place, and induced one Rhodes, a seed crusher, to embark in the business. After this the method of conducting the process

(1) The term *vitriol* was applied by the chemists to several salts, probably from their resemblance to glass, *vitrum.*

(2) Now called *Coleothar:* it is used as a paint. It is also prepared by mixing 100 parts of green vitriol with 42 of common salt, calcining the mixture, washing away the resulting sulphate of soda, and levigating the residuum. The polishing powder known as *jeweller's red rouge*, or *plate-powder*, is prepared by adding a solution of soda to one of sulphate of iron; and washing, drying, and calcining the precipitated oxide of iron in shallow vessels until it is of a deep brown-red colour.

The alchemists named the fixed residue of a distillation a *caput mortuum*, and represented it by a *death's-head*, under the idea that it was inert and useless; while the volatile matter which rose from such dregs being active and strong, was called the *animus* or *spirit*, and was represented by a bow, denoting strength or power; or, if it happened to be an acid spirit, then by a bow and barbed arrow-heads; the bow denoting strength, the arrow heads sharpness and swiftness of action; the barbs denoting the difficulty of extracting the acid from its combination, as barbed arrow-heads were difficult to extract from wounds.

became known, and acid works with lead chambers were established in many places.

We have seen that sulphurous acid, SO_2, is produced simply by burning sulphur in the air. Sulphuric acid, SO_3, is not so easily produced, although so simple in its composition. In fact, it is in order to make burning sulphur take up *three* instead of *two* proportions of oxygen that the extensive and costly arrangements of the sulphuric acid works are required. The chambers, or *houses*, as they are called, in which the acid is formed, vary in dimensions from 60 to 200 feet in length, and of proportionate height and width. They are raised 8 or 10 feet from the ground by means of brick piers, and are lined internally with sheet lead, which is not corroded by sulphuric acid at common temperatures. The lead which covers the bottom of the chamber should weigh from 8 to 10 lbs. per square foot, but lead of half that thickness is sufficient for the top and sides. The edges of the sheets are burnt together by the autogenous method described under SOLDERING; a tin solder being rapidly corroded. The thick lead which covers the bottom is turned up at the sides, so as to convert the bottom into a large trough about 12 inches deep. The floor is in some cases divided into compartments by means of ridges of lead, each compartment having its own exit pipe for drawing off the acid: and in other cases the whole chamber is divided into compartments by means of curtains of lead. See Fig. 2120.

There are 4 substances used in the production of sulphuric acid: viz. 1. *sulphurous acid*, formed by the combustion of sulphur in air. 2. *Nitric, nitrous* or *hyponitrous acid*, supplied by the nitre, and by means of which the sulphurous acid is enabled to take up another equivalent of oxygen. 3. Atmospheric air, which must be constantly renewed for the sake of its oxygen. 4. Water or steam, for the purpose of dissolving and retaining the sulphuric acid as fast as it is formed.

The sulphur which supplies the sulphurous acid is burned at one end of the chamber on a flat hearth of the oven O, Fig. 2120, which at first has a small fire

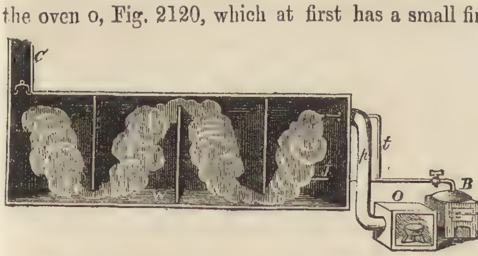


Fig. 2120. SULPHURIC ACID CHAMBER.

under it, but this is allowed to go out when the sulphur is fairly ignited. B is the boiler which supplies the chamber with steam. Immediately over the burning sulphur an iron pot is suspended or mounted on a tripod: it contains nitrate of potash or of soda mixed with the quantity of sulphuric acid required for its decomposition. From 8 to 10 lbs. of nitre mixed with 5 or 6 lbs. of sulphuric acid are used for every cwt. of sulphur. The heat of the burning sulphur distils off the nitric acid from the nitre, and the sulphurous acid and nitric acid vapours are conducted by means of a wide leaden tube *p*, from the furnace into the chamber, where these vapours meet with steam which is admitted near the same point by the tube *t*, and also by jets *j* distributed through the chamber: the steam causes a more intimate mixture of the gases, and assists the chemical changes which we will now describe.

Sulphurous acid gas, as already noticed, is capable of taking up another equivalent of oxygen from moist air; but it does so slowly, and for the purposes of the manufacturer the process is required to be quick. Sulphurous acid gas takes oxygen rapidly from nitric acid, NO_5, thereby reducing it to nitric oxide NO^2, a gas which, by mere exposure to air, takes up an additional supply of oxygen, generally 2 equivalents, so as to form nitrous acid, NO^4. Sulphurous acid also readily takes an additional supply of oxygen from nitrous acid, provided moisture be present. Two more equivalents of sulphurous acid thus become converted into sulphuric, and the nitrous compound becomes reconverted into nitric oxide, in which condition it is again fitted to abstract oxygen from the air, and thus to continue the action. Hence a comparatively small amount of nitre is sufficient to convert a large portion of sulphurous into sulphuric acid, and were it not that the nitric and nitrous gases are driven off with the nitrogen of the chamber by the chimney C, a small fixed quantity would suffice for a long time. In some works the valuable nitrous compounds are retained by passing the waste of the chamber through a stream of sulphuric acid, which absorbs them, and they are afterwards separated and returned to the chamber. In some works the chamber is divided into 3 or 4 compartments, by means of curtains of sheet lead proceeding alternately from the top nearly to the bottom, and from the bottom nearly to the top. It is supposed that these curtains detain the vapours, and cause them to advance gradually through the chamber, so that the sulphuric acid is almost completely deposited before the vapours reach the discharge tube C, Fig. 2120, which communicates with a tall chimney, or with the apparatus for separating the nitrous acid gas from the waste gas of the chamber.

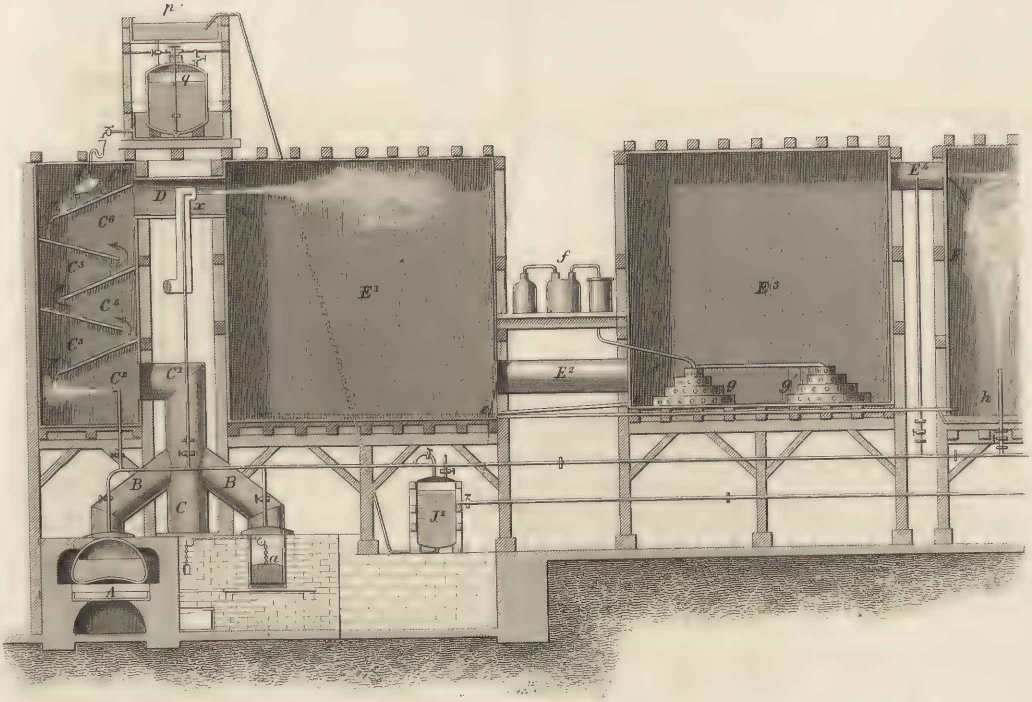
The mode in which this separation is effected in the French works, and some further details respecting the manufacture, will be understood by referring to the steel engraving. In some of these works not more than 3 lbs. of nitre are required to convert 100 lbs. of sulphur into 300 lbs. of acid: it is, however, common to employ free nitric acid instead of that acid in combination with potash or soda. The sulphur is burnt in the furnaces A and *a*, and the sulphurous acid is conducted by the leaden tubes B B into C, the capacity of which is equal to the sum of B B. A boiler for supplying steam is heated by the burning sulphur in A, and is supplied to the burning sulphur, and the combustion regulated by raising the sliding door *a* more or less. The sulphurous acid, together with the oxygen and nitrogen of the air, pass up the chimney into D, and so into the first chamber or *tambour* E E′, the jet of steam *x* assisting

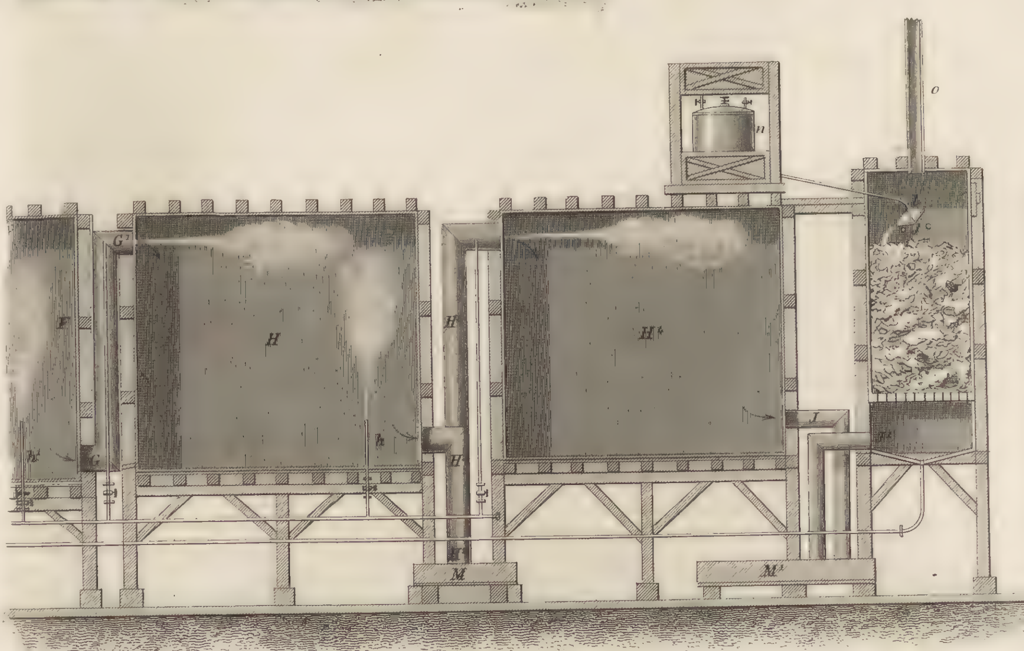
the draught of the fires A a, and the chemical reactions already noticed. The gaseous mixture impelled forwards by the constant generation of sulphurous acid and steam in A a, passes from the first chamber by the tube E_2 into the chamber E^3, where it comes in contact with nitric acid which is supplied from the vessels f to a couple of cascades $g\,g'$, down the steps of which it falls, and exposes a large surface to the sulphurous acid gas, which takes from it oxygen, and becomes converted into liquid sulphuric acid, reducing the nitric acid to the state of nitrous acid. The sulphuric acid thus formed is conducted by a small pipe into the first chamber E′, where the sulphurous acid and the vapour of water convert the nitric and nitrous acids which accompany the sulphuric acid, the one into nitrous acid and the other into binoxide of nitrogen, which is set free, but immediately combines with oxygen of the chamber to form nitrous acid, in which state it accompanies the different gases into the chamber E^3, and thence by the tube E^4 into the large chamber F F, the two ends of which only are shown in the engraving. A jet of steam in the tube E^4 acts as a motive force in urging the gaseous mixture into the chamber F, and also serves thoroughly to mix them together, and so determine the chemical reactions; 2 other jets $h\,h'$ playing up into the chambers produce similar effects. The gases which escape these reactions pass by the tube G G′ into the chamber H, where they are also exposed to jets of vapour G′ h. The gases which still remain unacted on descend from the chamber H by a tube H′ H^2, into a close reservoir M, divided into compartments in which the gases circulate and deposit their condensable vapours. Near one end of this reservoir ascends a pipe H^3, which conducts the vapours into the tambour H^4, whence they pass by J into another condenser M′, and from this they are discharged by a chimney into the atmosphere, the rate of discharge being regulated by a damper.

By this last contrivance there is still a loss of nitrous gas, which passes up the chimney. To prevent this loss the waste gases are made to pass through sulphuric acid of the density of 62° to 64° B., which allows the free nitrogen and oxygen to escape, but absorbs the nitrous acid gas, which can thus be introduced again into the chambers and exposed to the action of sulphurous acid and vapour of water. To effect these objects the gas, after having circulated through the condenser M′, where it deposits its moisture, passes into the chamber J′ j, and ascending through a grating steams up through a column of coke which is kept wet by the continual dashing of sulphuric acid upon it. The sulphuric acid is supplied by the vessel n, and is conducted by a pipe into a kind of double trough l balanced at its lower angle, and capable of oscillating between two pegs seen at j. The trough is balanced in such a manner that one of its divisions is always under the mouth of the pipe which supplies the sulphuric acid; but no sooner is one division filled with the acid than it tips over, discharges its acid upon the coke, and brings the empty division under the mouth of the supply pipe; to be in its turn filled and to tip over and discharge its acid on the coke on the other side. In this way the acid is dashed over the coke, which by its porous texture exposes a very great extent of surface, and while of the gaseous mixture which passes into the chamber J′, the oxygen and the nitrogen escape by the chimney o into the atmosphere, the whole of the nitrous gas is absorbed by the sulphuric acid, and is conducted by the pipe which proceeds from the sloping bottom of J′ into the reservoir J^2, whence it is raised by the pressure of steam upon its surface into a cistern p, which supplies a reservoir q, and this in its turn discharges the acid by a funnel into a second double trough q' balanced like the first l: from this trough the acid charged with nitrous vapour is dashed down upon a sloping shelf C^7, whence it pours down a series of other sloping shelves, meeting in its way the sulphurous acid gas from the furnaces A a, which, accompanied by vapour from the steam jet C^2, proceeds in the direction of the arrows. The joint effect of the steam and the high temperature is to disengage from the cascade of acid a portion of its nitrous acid, which in its turn converts a portion of the sulphurous acid into sulphuric. The sulphuric acid newly formed, as well as that from the cascade, is conducted by a pipe into the chamber E′, where it disengages nitric oxide, which gas in the presence of oxygen again becomes nitrous acid, and is instantly hurried on with the other gases and vapour into the other chambers, and assists in the production of fresh portions of sulphuric acid as already noticed. In this way by returning to the chambers the nitrous vapours which formerly escaped by the chimney, not only is the neighbourhood saved from the influence of the noxious caustic rain which these vapours formed, but the manufacturer saves above $\frac{2}{3}$ rds of the nitric acid, or of the nitrate of soda or of potash which is required in the operation.[1]

We now return to the process as conducted in Great Britain. A sulphuric acid house may be worked day and night without intermission, or only for a certain number of hours. In the one case the chamber must be supplied with a continuous current of fresh air, because it is the air of the chamber which supplies the oxygen required to convert the sulphurous into sulphuric acid, and not the nitrous acid gases obtained from the nitric acid or the nitre, these being merely the media of transfer between the oxygen of the air and the sulphurous acid. In the second case, or what is called the *intermittent* plan, the combustion of sulphur is carried on for 2 hours; steam is admitted, and the whole left to settle for an hour and a half: the conversion of the gases into acid then goes

(1) In Payen's "Précis de Chimie Industrielle," 1851, another method of condensing the nitrous vapour is described. It consists in passing the waste gases through a large series of bombaloes, constructed and arranged somewhat like a Woulfe's apparatus on a very extensive scale. The bombaloes contain sulphuric acid, which as it becomes charged with nitrous vapour is drawn off, and returned to the chamber E′, and acid from the more distant bombaloes is made to supply its place; fresh sulphuric acid being poured into the bombaloes last emptied. M. Payen has shown how the transfer of acid may be made self-acting by connecting the bombaloes together by means of syphons.





SULPHURIC ACID CHAMBERS.

on for 3 hours, during which time the drops of strong acid are heard rattling like hail-stones on the bottom of the chamber. The chamber is then opened for ¾ hour, to admit fresh air and to prepare for another charge. In a chamber of the capacity of 27,000 cubit feet 9 cwt. of sulphur are burned in 24 hours. The state of the interior of the chamber is ascertained by openings in the roof, each covered with a glass bell. When the interior of the glass does not appear thickly covered with drops, the proportion of steam is increased. A sample of the product may be taken out, and the depth of the acid liquid at the bottom of the chamber ascertained, by means of an opening in the side near the bottom of the chamber, made by pushing the lead inwards and prolonging it so as to dip beneath the surface of the liquid, as shown in Fig. 2121, and prevent the escape of gas. The temperature of the chamber ought to be maintained at 130° to 140° Fahr. If below 100° the formation of sulphuric acid is liable to be suspended, and a white crystalline compound to form on the sides of the chamber. This is called by the French "la maladie des chambres." Indeed it has been supposed that this crystalline substance must always be formed and afterwards decomposed in order to produce sulphuric acid at all. It is formed by the union of 2 equivalents of sulphurous acid ($2SO_2$) with 1 equivalent of nitrous acid (NO_4): but it separates into 2 equivalents of sulphuric acid ($2SO_3$) and 1 equivalent of nitric oxide (NO^2), whence this white crystalline substance has been named *sulphate of nitric oxide.* But, however this may be, supposing the process to be conducted successfully, the acid continues to be formed and to trickle down the sides of the chamber to the bottom, gradually increasing in density. When the density of the acid varies from 1·350 to 1·450 it is drawn off from the bottom of the chamber by a leaden pipe into large leaden boilers, where, by the action of heat, a portion of the water of the acid is driven off, and the strength of the acid thus increased. These boilers are made of large rectangular plates of thick lead, the edges being folded up so as to form pans of the depth of 10 or 12 inches. Each boiler rests on a close grating of strong iron bars, and has a separate fire. As the acid in the top boiler becomes stronger by the evaporation of the water, it is transferred by means of a syphon tube to the middle boiler, and thence to the lowest. When the acid has acquired the density of 1·650, or 1·700, it must be removed from the leaden vessels, because at a little over this strength the acid corrodes lead. In order to raise it to the commercial strength it must be concentrated in glass or platinum retorts, for which purpose it is removed from the boilers into coolers, or run through a long worm pipe surrounded by cold water. When glass retorts are used, they are arranged in a long gallery furnace in a double row, each retort being placed in a sand-bath supported by fire-tiles and furnished with a separate fire. The vapour given off usually contains some acid, especially when the concentration is nearly complete, and this vapour is conducted into the chamber or into the leaden boilers. In some sulphuric acid works near Salisbury, which the Editor visited a few years ago, and described in the second volume of his work on the "Useful Arts and Manufactures of Great Britain," the glass retorts were each of the capacity of 4 or 5 gallons, with the necks fitting on separately like the top of an alembic. The retorts were arranged in a double row of 16, and while in operation the parts of the retort projecting from the sand-bath were covered with a hood of tin plate. From 12 to 16 hours were required for the concentration: this being completed, the fires were extinguished and the retorts left to cool; after which the acid was drawn off into large brown earthenware vessels by means of a syphon of lead pipe, Fig. 2122, recurved at the shorter arm. This syphon was first inverted and filled with water; then closing the long end with the finger, the short limb was inserted into the body of the retort. On removing the finger, the water in the syphon was set in motion, bringing after it the acid. The water was caught in a small cup held under the end of the syphon; this flowed out with a gurgling sound, and the moment it ceased the cup was removed, and the acid appeared; it fell down into the deep jar in a full, smooth, quiet stream, very much resembling oil, and reminding one of the origin of the old name of *oil of vitriol*, applied to it from this circumstance. The acid was next transferred into large globular green glass bottles, called *carboys*, securely packed with straw in wicker baskets. Each carboy contained from 80 to 100 lbs. weight of the acid; the necks were closed with glass or earthen stopples, luted on with clay or loam, and tied over with coarse canvas. In this way sulphuric acid is sent into the market.

Fig. 2121.

Fig. 2122.

In the above works the glass retorts are found to answer very well. No retort is ever disturbed in its sand-bath while it remains entire; but when, from exposure to draught or to too much heat, a retort is cracked, it is removed at once, unless the crack is situated in the upper part, where it admits of patching with white lead.

In large acid works, where the quantities produced require the incessant working of the apparatus, this system of *glass-retorting* is not practicable. The danger and great loss arising from breakage induced the late Mr. Samuel Parkes to introduce stills of platinum, a metal which resists the action of sulphuric acid even at high temperatures. The stills are made of thin sheets of platinum soldered together with pure gold:[1] they are oval in shape, and of

(1) These stills are nearly all made in Paris, and are of the capacity of from 5 to 20 cwt.; they cost from 1,700*l.* to 2,600*l.* each; and although one of these retorts wears out in two or three years, yet it is found more economical in large works to use these costly vessels than the cheap and abundant material, glass.

The following calculations by M. Payen prove that where glass retorts of the capacity of 80 litres do not cost more than 1 franc 60 cen-

various sizes, and are preserved from the direct action of the fire by being set in cast-iron jackets, arranged over the flue of a furnace. The stills have platinum heads and beaks like common stills, and the beaks are inserted into leaden worms, in which the watery, sulphurous, and nitrous acid vapours given off during the concentration are condensed and conveyed to the water on the floor of the chamber.

When the acid is sufficiently concentrated in the platinum retorts, they are in some cases lifted off the fire, together with their iron jackets, and let down into a cistern of cold water. The boiling hot acid is in this way speedily cooled; but this clumsy and dangerous contrivance has been superseded in many works by a platinum syphon, Fig. 2123, one leg of which is twisted into a worm, and contained in a vessel of cold water V. The acid is cooled in passing through this worm, thereby rendering it unnecessary to disturb the retort. In order to fill this syphon, the shorter leg *t* is plunged to nearly the bottom of the still; the stop-cock *c* to the longer leg, or worm, is closed; the worm is filled with cold acid through the funnel *f*. The stop-cock to this funnel is then closed, and that at *c* suddenly opened; a quantity of acid then flows out sufficient to rarify the small portion of air in the upper part of the pipe, and to cause the hot acid to rise over the bend, and thus produce a continuous stream. The flow of the acid can be regulated by opening the stop-cock *c* more or less, and a constant supply of cold water may be kept up in the outer vessel V by the pipe *w*, which constantly supplies colder and heavier water to the bottom of the vessel V, while the water heated by the worm escapes through the side opening at *e*. The platinum retorts can be charged from 4 to 6 times a-day, which gives them a great advantage over glass retorts.

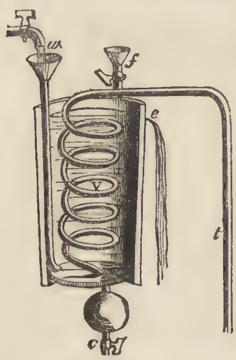


Fig. 2123.

The French method of concentrating the acid is more elaborate than the English. It is conducted by means of two leaden boilers or evaporators, B B′, Fig. 2124, and a platinum still P, as in the English method; but the first of the two boilers B is closed in at the top for the purpose of passing a current of sulphurous acid gas through the weak acid, and the close cover to this boiler is supported by curtains or partitions *c c*, which cause the sulphurous acid gas to travel by a circuitous route, and thus multiply the points of contact. The boilers are heated by the flues of the fire F, and the lead is supported by an outer casing of sheet iron, which also prevents the flame from coming in contact with the lead.

The acid to be concentrated is conveyed from the sulphuric acid chambers by a leaden pipe *p*, into the boiler B, and when it has attained a certain height therein it flows off by a waste-pipe. The sulphurous acid gas mixed with atmospheric air is conducted into the boiler from the furnaces A *a* in the steel engraving by means of a pipe *s*, Fig. 2124, and the gases which remain after having circulated through the boiler, together with vapour of water from the weak acid, are returned by another pipe *s′* into the chimney C′ D, and thence into the first chamber E E′ of the steel engraving. Within the chimney is shown a portion of this pipe enclosing a steam jet X, which acts as a moving power, setting the sulphurous acid gas in motion from the furnaces A *a* along the pipe *s*, through the boiler B in the direction of the arrows, then along the tube *s′* into the chimney D, and so into the chamber E E′. The sulphurous acid gas, mixed with common air and assisted by the heat of the flue *f″*, reacting on the nitrous and nitric acids contained in the weak acid in the boiler, forms sulphuric acid, and discharges by the tube *s′* into the chamber E E′ nitric oxide and nitrous acid, by which means the acid in the boiler B is denitrified, and the nitrous products, instead of being discharged into the air, are usefully employed in producing the reactions above described. The acid thus made stronger and purer is passed by a waste-pipe or a syphon *o* into the open boiler B′, which being nearer the fire F, is evaporated at a higher temperature, and concentrated to about 60° B. From this boiler the acid is passed into the platinum still by means of a syphon *n*, one leg of which is immersed in a beaked vessel, on raising or lowering which the discharge may be regulated or arrested altogether. The concentration of the acid in the platinum-still may be intermittent or continuous. In the first case the platinum-still is filled $\frac{3}{4}$ of its capacity as indicated by a floating-gage *g*, fresh acid being let in when the evaporation has lowered the surface of the acid in the still about $\frac{2}{10}$ths of the depth of the liquid. A brisk fire is kept up in F′, and the contents of the platinum-still are made to boil until the acid is sufficiently concentrated: this is known by the state of the acid water, which, distilling over from P in the state of vapour, is condensed by the worm *w w* con-

times each, as at Montpellier and the neighbourhood of large glass works, then glass retorts and platinum are about equal in cost; but when, as at Paris, Rouen, &c., a glass retort of the capacity of 80 kilogrammes costs 6 francs, and can only be used on an average 5 times, thus yielding 400 kilogs. of concentrated acid, the additional charge on every 100 kilogs. for expense of retorts is 60 centimes at Montpellier, &c., and 1 franc 50 centimes at Paris, Rouen, &c. In the latter case platinum is much less costly than glass. For example, in a platinum-still the body weighs 63 kilogs. the capital 6 kilogs. the adjutages, gage, &c. 2 kilogs. the syphon 10 kilogs.—making altogether 81 kilogs. and the cost about 80,000 francs (3,200*l.*). The interest on this sum, and the wear and tear, may be represented at 24 francs per day. This sum, spread over 4,000 kilogs., the quantity of concentrated acid produced daily by the platinum apparatus, causes an additional charge of 60 centimes on every 100 kilogs. of acid; for—

Kilog.		Fr.		Kilog.		Cent.
4,000	:	24	: :	100	:	60

Which shows an advantage of 90 cents per 100 kilogs. of acid in favour of platinum, when the retorts cost 6 fr. each; but when the retorts cost only 1 fr. 60 cents each, the expense of platinum and glass is the same, with the advantage in favour of platinum, that it is not liable to break by the heat, as glass is, and so entail loss of acid and danger to the operatives.

tained in the refrigerator R, and is received into a small reservoir lined with lead. The liquor thus distilled over contains at first much water, and very little acid, but in proportion as the acid in P loses water, its boiling point rises, more acid passes over, until at length acid containing only a single equivalent of water (SO_3,HO) would pass over. When such acid begins to pass over it is known that the contents of the still have attained that degree of concentration; but the process is nearly always arrested long before this limit is attained, unless where acid of extra strength is required, and which fetches a higher price in the market. It is, however, a loss to the manufacturer to produce such acid, not only on account of the smaller quantity which can thus be formed, but on account of the extra consumption of fuel and the high temperature, which towards the end of the process is near 620°: this induces a great amount of ex-

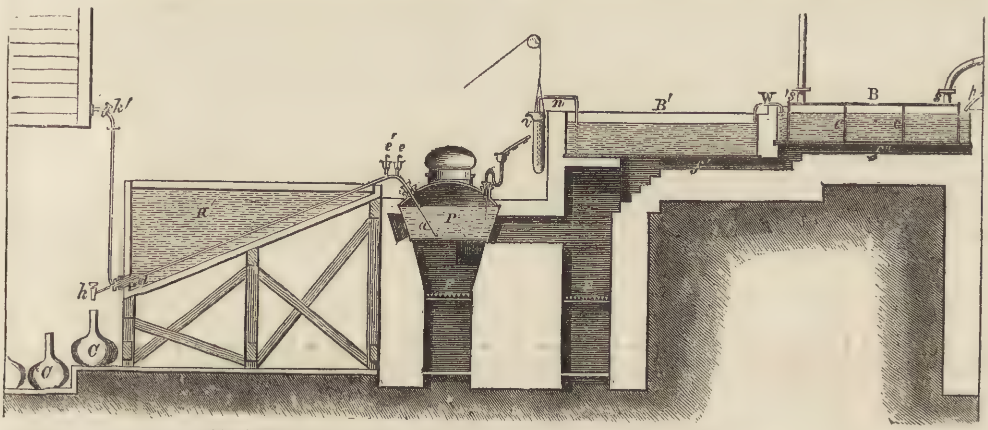


Fig. 2124. ELEVATION OF BOILERS FOR EVAPORATING SULPHURIC ACID.

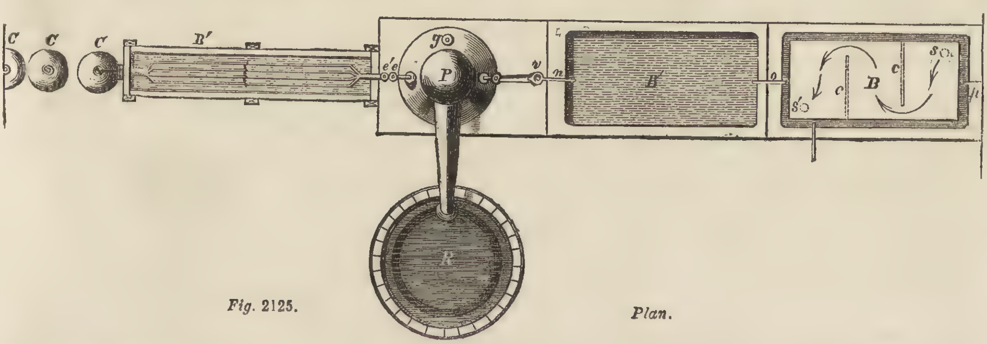


Fig. 2125. *Plan.*

pansion in the platinum, and endangers its cracking by its subsequent contraction on admitting a fresh charge. The operation is generally arrested when the condense water is of the sp. gr. 45° B. The acid in the still is then at 66° B., and forms the sulphuric acid of commerce.

The operation is, however, more economical when made continuous; for which purpose a constant stream of acid is made to pour into the still P, and a constant stream is at the same time being drawn off. In such case the product does not mark a higher degree than 64·5° to 65° B., and contains at least $1\frac{1}{4}$ equivalent of water. By this plan, however, the level of the acid in the still is kept constant, and the temperature is always the same, two conditions which contribute largely to the durability of the still. When the acid is sufficiently concentrated it is drawn off by means of the syphon *a e e′ d*, one leg of which, *a e*, is fixed into the boiler P by a screw-joint, its open mouth *a* nearly touching the bottom of P. When it is required to draw off the concentrated acid this syphon must be primed; for which purpose platinum plugs are taken out of the platinum cups *e e′*, and strong sulphuric acid being poured into one of them it gradually descends and occupies the long limb *e′ d*, while the air escapes by the other cup *e*. When the acid has risen up into one of the cups it is known that the long limb is full. The two plugs are then restored to their place, the cock K is opened, and the acid flows down the long branch of the syphon, which being immersed in a refrigerator R′ of cold water, which is being constantly renewed, reduces the acid to the temperature of the air, or thereabouts, and in order to increase the cooling-surface the syphon is divided into 2 or 4 branches. The acid is received into carboys C C or into a reservoir of lead.

The sulphuric acid of commerce is not quite pure. It contains persulphate of iron and sulphate of lead, and other fixed salts, some of which are deposited by repose. In order to obtain it pure, as it is required for many purposes of the laboratory, it must be distilled, and the most concentrated portion of the product reserved for use.

The sulphuric acid which has hitherto been referred

to is the *monohydrated*, or *one-watered* acid (SO_3,HO). It has a very strong attraction for water, and mixes with it in any proportion. As the mono-hydrated acid, however, is much less volatile than water, (not boiling below 600°,) these dilute mixtures may be concentrated by boiling, which drives away the surplus water, as already noticed. But by this method the acid can never be made stronger than the monohydrate, which boils at 620°, and distils without change. Acid containing less water than this can only be obtained by Valentine's process of distillation from vitriol, (as is practised at the present day in obtaining what is called the *Nordhausen acid;*) and the reason is, that the monohydrate, SO_3+HO, is a chemical compound, having properties not intermediate between those of its ingredients. The anhydrous, or waterless acid, SO_3, which is a solid, is extremely volatile, being entirely vapourized below 100°: yet, by uniting with 1 equivalent of water (the boiling point of which is 212°), it forms a liquid that does not evaporate below 600°. Compounds containing either more or less water than this, boil at lower temperatures, but with this difference, that the former give out only their surplus water, and the latter only their surplus acid; so that, although boiling strengthens the one, it weakens the other. At common temperatures, however, both kinds of acid become weakened, but in different modes; for while the common acid emits no vapour whatever, but greedily attracts moisture from the air, the Nordhausen acid emits dry acid vapour, which, meeting with the moisture of the air, instantly combines with it and condenses, forming the white fumes above mentioned; and this continues until both the liquid and the vapour (the former by losing acid, and the latter by gaining water) become reduced to the state of monohydrate, or common acid.

The *Nordhausen*,[1] or *fuming sulphuric acid*, as it is also called, is indeed a solution of anhydrous in the monohydrated acid. If the Nordhausen acid be carefully heated in a glass retort, it separates into anhydrous acid, which comes over in the state of vapour, and monohydrated acid, which remains in the retort. If these vapours be received into a small matrass with a long neck [see MATRASS, Fig. 1426], surrounded by a freezing mixture, they will condense under the form of long, white, brilliant needles, and form masses resembling asbestos. It fuses at about 77°, and boils at between 86° and 95°; its vapour is colourless. It is so greedy of water, that if a small piece of the acid be thrown into it, it produces a noise similar to that of a red-hot iron plunged into water; the hissing noise being produced by the great heat developed, the instant formation of steam by the contact of the acid and the water, and the condensation of the steam by the cold water closing in upon the bubbles. Regnault states that if a drop of water be allowed to fall into a bottle of the anhydrous acid, a flash of light is produced and an explosion. When the Nordhausen acid is exposed to a low temperature, a white crystalline substance separates, which is a hydrate containing half as much water as the common liquid acid.

(1) Nordhausen is in Prussian Saxony. The manufacture, however, is chiefly carried on near Prague, in Bohemia.

For the preparation of the Nordhausen acid, iron pyrites, or native bisulphuret of iron, are collected, washed in water for the purpose of getting rid of clay and earthy matters, and then calcined in clay retorts, similar in composition to glass pots [see GLASS, Fig. 1056]. The object of this operation is, first, to obtain sulphur, and secondly, to reduce the pyrites to that friable condition which is favourable to the subsequent process. The pyrites contain 53·33 per cent. of sulphur, half of which may be obtained by distillation in close vessels; but in such case, the heat must be sufficiently intense to fuse the monosulphuret which remains; but in so doing, the monosulphuret penetrates the body of the retort, and quickly destroys it. This inconvenience is avoided by employing less heat; but in such case only about 13 to 14 per cent. of sulphur is obtained, and there remains in the retort a sulphuret of iron composed of Fe_2S_3. The retorts are arranged in double rows, six in each row, and are heated by 3 to 6 fires, the whole arrangement being similar to that of gas-retorts [see GAS-LIGHTING, Fig. 1020]; and the vapour of sulphur which is disengaged is passed down a wide tube into cold water, where it is condensed. The residue in the retorts is exposed in heaps to the action of the atmosphere, and in the course of some years it undergoes a slow combustion, the sulphur and the iron absorb oxygen, the one forming sulphuric acid, and the other oxide of iron: the combination of these two compounds forms sulphate of iron, or green vitriol, which is obtained by washing the pyrites with water, and evaporating the solution. The mother liquors resulting from many similar operations are slowly evaporated; they deposit a basic sulphate of peroxide of iron, and retain in solution a mixture of sulphate of protoxide and sulphate of the sesquioxide of iron. The solution is evaporated nearly to dryness, and is lastly dried by the waste heat of the furnace, during which operation the protosulphate becomes oxidized by exposure to the air.

The furnace used in the distillation of the green vitriol, is a long gallery, containing 2 or 3 rows of 100 retorts in each, heated by the flame of a single fire. Each retort R R, Fig. 2126, is about 8 inches in diameter, and 32 inches long, and communicates with a receiver C of the same capacity, and of similar form. 200 retorts in the course of 48 hours, during which about 1½ ton of lignite is burnt as fuel, decompose about 560 lbs. of green vitriol. Vapour of water is first disengaged, and this is allowed to escape; then sulphurous acid and oxygen; and after these sulphuric acid, partly anhydrous, and partly hydrated, which is collected. About

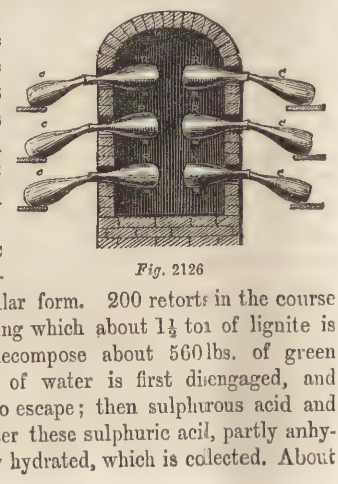


Fig. 2126

225 lbs. of this mixed acid is thus obtained, and about 282 lbs. of peroxide of iron or colcothar remain in the retorts.

Of late years a similar acid has been obtained in France, by distilling dry bisulphate of potash, or of soda, in earthenware retorts.

The chief use of the Nordhausen sulphuric acid is to make the solution of indigo so much used in dyeing blue colours. 4 parts of the fuming sulphuric acid dissolve 1 part of indigo, which is soluble in not less than 8 parts of common sulphuric acid; not only is the excess of acid lost, but its presence exerts an injurious action on the dye stuffs, and the articles to be dyed.

Iron pyrites is also used in the manufacture of ordinary sulphuric acid, as a source of sulphur, for the production of sulphurous acid. It is applied in two ways: in the first, the pyrites are washed at the stamping mill, and then spread in layers of about 2 inches deep, on plates of iron heated to redness, in a furnace similar to that shown at A or *a* of the sulphuric chambers, represented in the steel engraving. The pyrites is frequently stirred with an iron rake, for the purpose of renewing the points of contact with the draught of air; and after 6 hours the charge is let down into a cavity under the furnace, where it continues to burn for some time, and furnishes sulphurous acid, which passes up the chimney C′ D, and so into the chamber E′.

In places where fuel is scarce, the second plan is adopted, viz. to make the sulphur of the burning pyrites serve as fuel to a new charge. For this purpose a kind of running kiln, Fig. 2127, is used; a fire is lighted on the hearth sufficient to raise the

Fig. 2127.

interior of the furnace to a red heat; the first charge of pyrites, P, previously reduced to small lumps, is then filled in through an opening *o* in the top, and as it becomes ignited, fresh quantities are gradually added, until a height of nearly 3 feet is attained. The supply of air is regulated by the sliding door D, and as the pyrites is thoroughly burnt, they are hooked out by means of a long iron rod from between the bars, and they fall into the ash pit below. As the charge sinks in the furnace, more pyrites is added through *o*. Six of these furnaces are arranged round a central shaft, into which they discharge their products of combustion, consisting chiefly of sulphurous acid and air, by channels such as *t*, and from the central shaft the sulphuric acid chambers are supplied with sulphurous acid. For further details we must refer to Payen's "Chimie Industrielle."

In addition to sulphurous acid, SO_2, and sulphuric acid, SO_3, sulphur and oxygen combine in other proportions. *Hyposulphurous acid*, S_2O_2, is interesting, from the property of hyposulphite of soda dissolving certain insoluble salts of silver, such as the chloride, on which account it is of importance in PHOTOGRAPHY, as noticed in that article. The acid has not been isolated, but by digesting sulphur with a solution of sulphite of potash or soda, a portion of sulphur is dissolved, and the liquid by slow evaporation yields crystals of the new salt. *Hyposulphuric acid*, S_2O_5, *Sulphuretted hyposulphuric acid*, S_3O_5, and *Bisulphuretted hyposulphuric acid*, S_4O_5, do not require further notice in this place.

Sulphur combines with hydrogen, forming *sulphuretted hydrogen*, or *hydrosulphuric acid*, HS. It is a frequent product of the putrefaction of organic matter, both animal and vegetable; and it occurs in certain mineral springs. It is readily prepared in a gas bottle, such as is used for making common hydrogen, by the action of dilute sulphuric acid on sulphuret of iron, or of dilute hydrochloric acid on sulphuret of antimony. The action will be understood in either case from the following diagrams:—

Sulphuret of iron . {Sulphur, Iron} — Sulphuretted hydrogen.
Water.................. {Hydrogen, Oxygen}
Sulphuric acid — {Sulphate of oxide of iron.

Hydrochloric acid {Hydrogen, Chlorine} — Sulphuretted hydrogen.
Sulphuret of antimony .... {Sulphur, Antimony} — Chloride of antimony.

Sulphuretted hydrogen is a colourless gas, with an offensive odour resembling that of rotten eggs; a minute portion of it is sufficient to taint the atmosphere of a large room. It is instantly decomposed by chlorine; a small quantity of which, as evolved from chloride of lime by itself, or by the addition of a little dilute muriatic acid, will instantly clear a room of the sulphuretted hydrogen present. Sulphuretted hydrogen is not irritating, but narcotic; it is highly poisonous; an atmosphere containing $\frac{1}{100}$th of it, is sufficient to kill a dog, and $\frac{1}{1200}$th of it will destroy a bird. Men employed in emptying cesspools are sometimes seized with asphyxia, from the presence of this gas. The best remedy is to pour a little strong vinegar in a plate, and sprinkle upon it powdered chloride of lime, and hold this under the nostrils of the patient. Sulphuretted hydrogen burns with a blue flame, the results of combustion being water and sulphurous acid; its sp. gr. is 1·171, air being 1·000, and 100 cubic inches of it weigh 36·33 grains. It becomes liquid under a pressure of 17 atmospheres at 50°. Cold water dissolves from 2½ to 3 times, and alcohol 5 to 6 times its own volume of this gas, and the aqueous solution reddens litmus paper. The solution is a most useful test, but it cannot be preserved, as the oxygen of the air soon spoils it; it is therefore best to make it as it is wanted, for which purpose a small bottle, with a bent tube in its cork, is supplied with sulphuret of iron

and water, and when required for use, the addition of a few drops of sulphuric acid will evolve the sulphuretted hydrogen. The bottle must be emptied when enough gas has been obtained for the purpose required. "There are few re-agents," says Mr. Fownes, "of greater value to the practical chemist than this substance; when brought in contact with many metallic solutions, it gives rise to precipitates, which are often exceedingly characteristic in appearance, and it frequently affords the means also of separating metals from each other with the greatest precision and certainty. The precipitates spoken of are insoluble sulphurets formed by the mutual decomposition of the metallic oxides or chlorides, and sulphuretted hydrogen, water or hydrochloric acid being produced at the same time. All the metals are, in fact, precipitated, whose sulphurets are insoluble in water, and in dilute acids." The best test for the presence of sulphuretted hydrogen, is paper wetted with a solution of acetate of lead, which is blackened by the smallest trace of the gas.

Bisulphuret of carbon, CS_2, is formed by passing the vapour of sulphur over red hot charcoal, in a porcelain tube; or by distilling 6 parts of yellow iron pyrites with one of charcoal. The product is collected in a receiver cooled to 32° or lower, and should be purified by re-distillation at a low temperature, with chloride of calcium; it then forms a transparent, colourless, highly inflammable liquid, of great refractive and dispersive power; its density is 1·272; its boiling point 110° Fahr., and it emits vapour of considerable elasticity at ordinary temperatures; it produces a very low temperature by its evaporation, especially in vacuo where —80° has been obtained by its means; it does not itself freeze at —60°; it has a pungent taste, and a peculiar fœtid odour. It dissolves sulphur freely, and deposits it on evaporation in beautiful crystals. It also dissolves phosphorus in large quantity, and the solution is sometimes used to give a thin film of phosphorus to delicate articles intended to be coated with metals. [See ELECTRO-METALLURGY.] The chief demand, however, for bisulphuret of carbon, is as a solvent of india rubber, for softening that substance, and also for vulcanising it. [See CAOUTCHOUC.] Hence the demand for bisulphuret of carbon has of late years greatly increased, and to meet this demand it is manufactured on a large scale, the apparatus for which, by M. Peroncel, is described in Payen's "Chimie Industrielle."

Chloride of sulphur, SCl, also used in the vulcanization of india rubber, is prepared by passing dry chlorine over the surface of sulphur, melted in a glass retort. The chloride distils over into a cooled receiver, as a mobile liquid of a deep orange yellow colour, and disagreeable odour; it is decomposed by water; and as it dissolves both sulphur and chlorine, it is not a very definite compound. A *perchloride* is formed by exposing the chloride for a considerable time to the action of chlorine.

SULPHURATION.—See SULPHUR.

SUMACH.—See LEATHER.

SURVEYING. The art of ascertaining and registering the horizontal extent and forms of any parts of the earth's surface, whether of land or water, and whether bounded by natural features, human works, or conventional lines. No art has been so prolific in giving birth to science as this, for the whole range of mathematical, *i. e.* of *exact*, knowledge and workmanship has ever hinged on the advance of the chief branch or rather trunk of mathematics, the name of which, *geometry*, to this day indicates its original purpose, *land-measurement;* and it is the extension of this word *geometry* to designate the whole resulting *science* that has necessitated the new word *surveying* to take its place as the name of the parent *art*. So that surveying now means what geometry primarily meant.

That this art began in Egypt is commonly believed and hardly to be doubted, since not only did the yearly inundation in that country interfere with the protection of artificial boundaries, but it was the first valley that required them; agriculture having there first come to occupy the whole available land, and therefore first led to the exact division and appropriation of it; at one time (as we learn from the book of Genesis) in the hands of the people at large, and afterwards, by a special intervention of Providence, so centralized in the monarch, as to enable the prophet-statesman, by a lasting charter and by one measure, to perpetuate at once strength of government and certainty of supplies, with popular immunity from extortion. To this day Egypt consists entirely of crown land, inalienable and yet unchargeable with more or less than a fixed portion of the produce: not indeed the same that at once left the poorest worth cultivating, and checked individual avarice by the unprofitableness of sub-letting; but the 20 per cent. (Gen. xlvii. 24,) is known to have continued in its integrity down to the times of the Ptolemies; and of course the due assessment of this Josephian tax necessitated and powerfully advanced this art, the mother of so many sciences.

Hence it was in Egypt, by observations of latitudes at the two ends of the country, and estimation of the distance in furlongs, that the first and only ancient attempt to settle the curvature (and hence the size) of the globe, was made, by Eratosthenes, about 230 B.C. This problem, however, the utmost triumph of surveying, and which calls together all its latest refinements, could not be performed with any certainty until within the last century.

In England, the measurement of land is performed with a measure called after its inventor, *Gunter's chain*, contrived to simplify the computations as far as our peculiarly clumsy traditional units of area and length would admit. The smallest, indeed, of the three units of area used for land, the *perch*, is the square of one of our units of length, the *rod* or *pole;* but the two higher ones, the *rood* and *acre*, correspond to the squares of no lineal measures. The acre, however, being a tenth of a square *furlong*, and therefore, when disposed in a strip one furlong in length, requiring to be a tenth of a furlong wide, determined this latter fraction as the most convenient length for the chain, and it con-

tains exact though awkward numbers of all the lesser units, viz. 4 *rods* or *poles*, = 22 *yards*, = 66 *feet*, = 792 *inches*. Its length is then the 80th of a mile, or 10th of a furlong; and its square the 10th of an *acre*. $2\frac{1}{2}$ such squares are a *rood* or quarter acre, and the 40th of this, or square of a quarter-chain (*i. e.* such a square as the chain will go round) is a *perch*, or square *rod* or *pole*, the smallest unit used for cultivated land.

A division of this chain into feet would evidently fail to mark the pole, which is $16\frac{1}{2}$ feet. Moreover, the relations of the yard or foot to the areal measures (4840 square yards = 43560 square feet in an acre, and $272\frac{1}{4}$ square feet in a perch,) are so absurd, that a chain thus divided would necessitate about 5 times the natural amount of calculation for finding areas. Although some chains, such as are used for distance-measuring alone, have 132 half-foot links, (which are a convenient length for uniting lightness and stiffness,) the proper chain is divided into 100, so that all the measurements may be expressed in one denomination, *links*, and by simple omitting the last two figures, the chains are seen, thus: 2135 links = 21 chains, 35 links. And as all calculations of area thus lead to a result in *square links*, which are a 10,000th of a square chain, or 100,000th of an acre, they show at once, by omitting their last *five* figures, the acres; and the five figures cut off, if multiplied by 4, show, similarly omitting the last five resulting figures, the odd roods if any; and the five cut off from these, again multiplied by 4, give, omitting the last *four* of the result, the odd perches. The four cut off to leave this are decimals of perches.

The *link*, then, is a measure of 7·92 inches, only introduced for the sake of abridging calculation. Between each two links are one, two, or three small rings, according to the degree of flexibility desired in the chain; and for rough work it should have 200 half-links, to avoid risk of bending them. The middle of the chain is marked by a round piece of brass, the 40th link from each end by a four-fingered bit; the 30th, 20th, and 10th, by a triple, double, and single finger respectively; and the 25th by some other mark; which renders the counting of odd poles or links a momentary operation. The chain can be pulled on almost any ground perfectly straight, and the follower of it can direct him who leads, to place a pin in the straight line with the mark towards which they are proceeding; or, in continuing a previous line, the leader can place it himself correctly by the marks defining that previous line. He has at starting 10 of these pins, which the follower picks up as they are left, so that at the end of every furlong they must be retransferred to him, and an entry of 1,000 made in the book (all numbers in which are understood to be links). As *horizontal* distance only is to be measured, and it is hardly possible to stretch a whole chain straight in the air, sloping ground must be measured by half or quarter chains at a time, unless the slope be regular enough to enable its inclination to be measured by some kind of mason's level, and a reduction made from the length along the ground, by a table which shows the reduction per 1,000 links for given degrees of slope (*i.e.* the versed sine of those degrees to a radius of 1,000). But the difference between horizontal and inclined distance, especially on slight hills, is always far less than we are led to estimate it.

Surveying should first be learned with the chain alone, and the most elementary subject, a single enclosure, with four straight sides, may always be thus mapped by measuring each side and one diagonal. It is obvious that these five dimensions, transferred to paper, will give one definite figure only; and this operation is called *plotting* it. A perpendicular to the diagonal, A B, Fig. 2128, must then be dropped

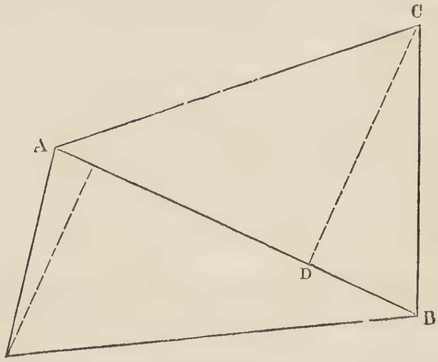


Fig. 2128.

from each of the other angles, and measured by the scale which is used for plotting; and half the sum of these, multiplied by A B, gives the area of the two triangles whose common base is A B, that is, of the whole field. It is plain, that any figure of straight sides, however complex, can similarly be divided into triangles less in number than the sides by two; and every side of each triangle being measured in the field, their perpendiculars can be measured on paper.

For a *curved* boundary, however, it is necessary to measure a *straight* line as near it as may be convenient (which, in a simple curve, will resemble a string to a bow), and make this straight line, which need not always have its extremities at corners of the field, a side of one of our triangles, and while measuring it, to take also a series of distances from different points of it to the curve. These are called *offsets*, and must be perpendicular to the straight line, which may be ensured nearly enough by eye, if we measure them with rods placed against the chain without disturbing it. One must be carried to every sudden bend or break in the curve; but if it have none, they will be best repeated at regular intervals of a chain, or more or less, according to the exactness desired. In either case, the number of links from the beginning of the line at which each is placed, must be noted, as well as its length. We have then plainly the means of plotting as many points of the curve as there are offsets, and through these points its map may be drawn, as shown in Fig. 2129. The area, then, of each space between two offsets, is taken as if the line joining their ends were straight, whence the necessity for placing one at every decided break. It is found by multiplying the half sum of the two offsets by their interval. Where any number of intervals are equal, it will easily be seen how the whole

area for that length can be abridged into one operation. The whole offset space is then added or sub-

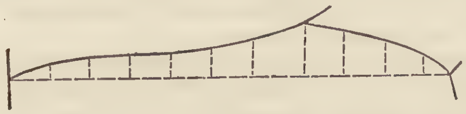


Fig. 2129.

tracted, according as it lies without or within the triangulation of the field.

These two principles embrace the whole practice of area computing, and no other can ever be necessary. Moreover, means of registering all this, and all things necessary to plotting a finished map, without sketching any map at all, have been contrived as follows:—Each page of the field-book is divided into 3 columns, and we begin at the *bottom* of the *middle* one, in which we note progressively upwards all measures and memoranda relating to the lines along which we chain. We call the starting-point A; the end of the first line chained, or beginning of the second, B, and so on; that, as each turning-point has a separate letter, it may be known when we have returned to a point visited before; and at the end of every line we note by one of two marks, such as *r* or *l*, whether our turning into the next line be to the right or left. The two side columns are reserved for the lengths of offsets, which we write to the right or left, according as they lie with regard to the line along which we are chaining; and hence the reason for adding our notes upwards from the bottom of the page. Any memoranda of objects passed are also written in the right or left columns.

There is no difficulty in extending this method to several adjacent enclosures or a whole district, only observing that the longer our straight lines the better and more exact will the work be, so that the principal ones should, in this case, be quite independent of fences or boundaries, (unless some remarkably long straight pieces thereof should lie conveniently for the purpose,) and should be extended without a turning as far as possible within the limits of the survey. Every fence crossed must be noted in the middle column, with the number of links at which it occurs. It is further to be kept in mind that all triangles are plotted more exactly the nearer they approach to *equilateral* ones, so that the largest especially must be as nearly so as circumstances admit, and are *ill-conditioned* in exact proportion as their angles differ more from 60°.

The simplest instrumental aid beyond the chain, is some means of finding the spot in any line from which a perpendicular thereto will reach a given distant point. The saving of measurement by this will appear by considering that in Fig. 2128, (the only use of chaining A C, C B, being to define the place of C,) if we could know in the field on what point D, of the chained line A B, a perpendicular to it from C would fall, we should only have to measure this perpendicular, instead of the two lines A C, C B, both longer than itself. *Three* lines instead of *five* would thus suffice to plot and thoroughly survey the whole field; and further, as the perpendiculars, and not the sides, are directly influential on the area, it would be more satisfactory to measure them in the field than on a paper plan. The oldest expedient for this is the *cross-staff*, whose simplest form has for the head a mere board with two deep saw-cuts across it at right angles; accuracy depending of course on the squareness of these angles. This being planted in some part of A B, and so turned that through one of its grooves we can see A in one direction and B in the other, we shall through the other groove see to the right or left of C, and must accordingly move the staff forward or backward along A B, until by a few trials we find the spot where it will permit the three marks A B C to be seen. This has been superseded, however, by the *optical square*, a far more elegant and expeditious instrument, which need not be more expensive, and may insure more accuracy than any cross, however large, while it may be made so small as to be carried in the waistcoat pocket. It consists of two plane pieces of silvered glass, immoveably fixed in a sort of box in that position which the glasses of a sextant have when its index is at 90°, viz. inclined 45° to each other. Half the silvering of one glass being removed, the eye directed to it sees at once an object directly in front, *through* the transparent portion, and another object reflected from the other glass to this one and thence to the eye; and this object must be 90° distant from the former; so that by walking along the part of A B where we expect the perpendicular to fall, with the instrument at our eye, and A in sight through it, various objects about C will successively appear reflected, and when the image of C itself becomes coincident with A, we are at the right spot.

Single fields, and even the main features of a large district, as far as they are visible *over* each other, (as in hills surrounding a plain, or lower country surrounding a flat-topped eminence,) may also be plotted with moderate accuracy by measuring only *one* line upon the central plan, or central elevated platform, and setting up, first at one end thereof and then at the other, a *plane table* or drawing-board with paper on it. A ruler must be provided with two *sights* or vertical slits in plates of metal, with a hair or hair wire stretched upright in each, exactly over the drawing edge of the ruler, which edge must be kept against a fine needle stuck in the drawing-board, and turned about so that the various objects whose places are to be plotted may be successively seen through the sights and in a line with the two wires. When so seen, a line is drawn towards them from the needle, by the edge of the ruler. The table being moved to the other station, the needle is also moved a space representing on the scale of the intended map the measured distance of the two stations apart. The table being first set so that the line towards the former station is correct, all the same objects are again observed, and it is plain that the lines radiating to them from the new place of the needle will meet the former lines at the true places of those objects on the map.

This is in fact a *trigonometrical* survey, in so far as

it is not only by measurement of *triangles,* as every survey is, but depends on the observation of their *angles,* instead of their *sides,* of which only one, the common base of all the triangles, is measured. The angles, indeed, are not *measured,* but only *transferred* from the ground to the paper, where they could then be measured with a common protractor if necessary, which, however, it is not, for computation of areas or any other purpose. Now the advantage of measuring the *real* angles by a graduated instrument, (*i. e.* a protractor of the utmost possible delicacy,) is not to obtain a more exact plot, (for this will always be limited by the delicacy of the protractor used on the paper,) but to make the ascertaining of all the unmeasured lines, and hence of the areas, *independent* of the plotting altogether; to make it matter of computation only, from the tables of trigonometrical ratios, which may be carried to any degree of minuteness. In proportion to the accuracy attained in the measurement of the angles, is the number of triangles that may be attached to each other, and hence the extent to which a single survey may be carried from one measured base; for the principal or first order of triangles are of course made as large as the situation of hills will permit, their angles being on the chief eminences, and often more than 100 miles apart.

The instrument now exclusively used, we believe, by Englishmen for these measurements, is the THEODOLITE,—which see.

SUSPENSION BRIDGE.—See BRIDGE, Sect. V.

SWEEP-WASHING is the art of recovering the particles of gold and silver out of the *sweep* or ashes, earths, sweepings, &c. of the jeweller's workshop. In making a wash, the old crucibles, and even the bricks of the furnaces, are pounded for the sake of the minute portions of precious metal which they may contain. The water in which jewellers wash their hands is collected in a tub: the dirt and mud settle by repose, and the water above it is drawn off every few days, and when a sufficient quantity of sediment is collected the tub is carried off in the sweepwasher's cart.

The various refuse collected by the sweepwasher are well ground and mixed together, and are then put into large wooden basins, and washed several times, and in several waters, which run off by inclination into troughs at a lower level, carrying with them the earthy substances and the finest particles of metal, leaving behind those which are visible to the eye and can be taken out by hand. The finer parts which pass away with the earthy substances are recovered by means of mercury and a washing-mill. The mill (which is similar to that described under METALLURGY, Fig. 1451) consists of a large wooden trough, at the bottom of which are two metal portions, the lower of which is convex, and the upper, which is in the form of a cross, concave. At the top is a winch, placed horizontally, by which the upper piece is made to rotate, and at the bottom is a hole closed by a bung, for letting out the water and earth when sufficiently ground. In having a wash, the trough is filled with water, 30 or 40 lbs. of mercury are poured in, and 2 or 3 gallons of the matter remaining from the first lotion. The winch is then turned, and the upper mill-stone, by its revolutions, grinds the sediment and the mercury together, and the particles of gold and silver are readily dissolved by the mercury. This work is continued for 2 hours, when the bung is removed, the water and earth run out, and a fresh quantity admitted. The earthy substances are usually passed 3 times through the mill: the mercury is then taken out, washed in several waters; put into a tick-bag, pressed to get rid of water and loose mercury; the remaining mercury is sublimed, and the alloy of gold and silver is parted with nitric acid. See ASSAYING.

Two or three of the washing-mills may be worked together at different levels, as noticed under GOLD. Mr. Gill states, that "a mill was established at Geneva for washing the goldsmiths' and jewellers' sweepings gratis. It consisted of a flat circular ring of cast-iron, placed horizontally, and having a circular groove or channel, in which 2 heavy cast-iron runners were made to turn by the power of horses. The sweepings being put into the channel with mercury, water was made to enter the channel on one side and pass off on the other side continually during the action of the machine. We said the proprietors professed to grind the sweepings *gratis;* but, in fact, the water carried off with it into proper receptacles placed in an adjoining room so much gold, as to render the concern a highly lucrative one. If we are not mistaken a similar machine is, or at least was, established by foreigners in London some time since."[1]

SWELL. See ORGAN.

SYNTHESIS (σὺν and θέσις, putting together), a term applied to that chemical action by which bodies are united into a chemical compound. Under ANALYSIS it was shown that alum consists of alumina, potash, sulphuric acid, and water: the same thing may be shown by synthesis, for by combining these 4 constituents in proper proportions, alum is produced. Thus the chemist is doubly satisfied with the correctness of his analysis when he can reproduce the body analysed by synthesis. This, however, he is not able to do in all cases; for there are a large number of bodies, especially the organic, which cannot be produced synthetically.

SYRINGE, a pipe or tube (σύριγξ), so arranged as to draw up a liquid and then inject it with violence. A syringe is only a single acting pump, and the water ascends in it on the same principle as in the common pump. [See PUMP, Fig. 1772.] For particular purposes syringes have some special construction, as in garden syringes, which are often of large size, jets are provided for the purpose of scattering the water in the form of fine rain. The syringes used in surgery are often carefully and accurately made, so as not to entangle air with the liquid drawn up, and to inject the latter with a regulated velocity. The *stomach-pump* is a syringe, with a flexible tube attached, which is passed into the stomach of the patient, with

(1) Technical Repository, vol. viii. 1826.

a guard for fixing between the teeth to preserve the tube from injury: a branch pipe is also attached to the syringe, for supplying it with liquid from a vessel when the syringe is used for injection, and to provide a channel for the escape of the liquor when the syringe is employed to empty the stomach. The valves are so arranged that the instrument will act either way. It is usual, first, to inject a diluent into the stomach, and then to pump it back again together with the matter which it is desired to remove. Or a fluid may be injected into the stomach until it is involuntarily discharged by the mouth, and the operation is continued until the fluid is no longer contaminated. The *exhausting* and *condensing syringe* for aeriform fluids is described under Air, Fig. 19.

SYRUP. See Sugar.

TABBYING, a variety of Calendering, in which the rolls are engraved so as to impart to the silk or stuff the effect of *waves*, from the unequal action of light on the fabric, so that the rays are very unequally reflected.

TACK. See Nail.

TAFFETY, or Taffeta, a silk stuff, smooth and glossy, plain, coloured or striped with gold, silver, &c., chequered, flowered, &c. See Weaving.

TALC is one of the hydrous silicates of magnesia. [See Magnesium.] It occurs *crystallized* and *massive*. The primary form of the crystal is a rhomboid, but it usually occurs in the secondary form of hexagonal laminæ, and even in long prisms. The cleavage is distinct and perpendicular to the axis. It is readily separable into thin plates, which are flexible, but not elastic. The lustre is pearly, and the colour a shade of light green or greenish white: sometimes it is silvery-white, and also greyish-green and dark olive-green. It is unctuous to the touch, and is easily impressed by the nail,—the hardness being equal to 1 or 1·5: the density varies from 2·7 to 2·9. Crystallized talc occurs in small quantity in serpentine rocks, accompanied by carbonate of lime, actinolite, steatite, and massive talc, &c. The massive varieties occur in beds of micaceous schist, gneiss, and serpentine. Massive talc or soap-stone reduced to powder forms what is called *boot-powder*. Bootmakers dust the inside of a tightly fitting boot with this substance to enable it to be drawn on easily. This substance was largely used some years ago at Manchester, as one of the ingredients for converting an inferior low-priced tea into a high-priced one. The manufacturers of boot-powder, surprised at the large demand for their article by one house, and that house a tea-warehouse, made some inquiries, which led to sufficient publicity to put a stop to the fraud. See Tea.

Indurated talc occurs in primitive mountains, in clay-slate, and serpentine; it is massive, of a greenish-grey colour; the structure schistose and curved; it is of a shining and sometimes pearly lustre; translucent, soft, and rather unctuous to the touch, and of the sp. gr. 2·9.

Lamellar talc contains, according to Vauquelin, silica 62 per cent. magnesia 27, alumina 1·8, oxide of iron 3·2, and water 6. Nearly allied to mica, are steatite, chlorite, and other magnesian minerals. See Magnesium—Steatite.

Talcose slate resembles mica slate [see Mica], but has a more greasy feel from its containing talc instead of mica. It is of a light-grey or dark-greyish brown colour; it breaks into slabs, which are used for fire-stones. *Talcose rock* is a kind of quartzose granite, containing more or less talc: it is intersected by veins of white quartz, and also contains chlorite. "The talcose rocks," says Dana, "are, to a great extent, the gold-rocks of the world. This rock contains the topaz of Brazil, and also euclase, and many other minerals."

TALLOW. See Candle—Oils and Fats.

TAMARIND, the fruit of a tree (*Tamarindus Indicus*) growing in the East and West Indies to the height of 30 or 40 feet. When the fruit is ripe the shell or epicarp is removed, and the fruit placed in layers in a cask, boiling water being then poured over it. Another plan is to put alternate layers of tamarinds and powdered sugar in a stone jar. Tamarinds are imported both raw and preserved. Tamarind pods are from 3 to 6 inches long, and more or less curved: they consist of a dry, brittle, brown external shell, within which is the acidulous, sweet, reddish-brown pulp (which is the useful part) penetrated by strong fibres. Within this is a thin membranous coat enclosing the oval brown seeds. The pulp as analysed by Vauquelin contains citric acid 9·40, tartaric acid 1·55, malic acid 0·45, bitartrate of potash 3·25, sugar 12·5, gum 4·7, pectin 6·25, parenchyma 34·35, and water 27·55. The pulp allays thirst, is nutritive and refrigerant, and in full does laxative. "An infusion of tamarinds," says Pereira, "forms a very pleasant, cooling drink, as does also tamarind whey." Infusion of senna with tamarinds is a useful laxative.

TAMPING. See Stone.

TAN. See Leather.

TANNIC ACID. See Leather.

TANNING. See Leather.

TANTALUM (Ta 185,) also called Columbium, a rare metal found in combination with the oxides of iron and manganese, and also with yttria in the Swedish minerals *tantalite* and *yttro-tantalite*. The metal has been obtained in the form of a black powder resembling iron; its sp. gr. is about 6. The oxides have acid properties: *tantalous acid* contains $Ta\,O_2$, and *tantalic* or *columbic acid*, $Ta\,O_3$.

TAP. See Screw.

TAPESTRY. See Weaving.

TAPIOCA a form of Starch, prepared in South America from two species of *Janipha*, or the *bitter* and *sweet cassava* or *manioc* roots. From the facility with which the bitter cassava can be rasped into flour, it is cultivated almost to the exclusion of the sweet variety, which contains in its centre a tough fibrous ligneous cord, which is absent in the bitter variety. The latter, however, contains a highly acrid and poisonous juice, which is got rid of by heat or by fermentation, so that the cassava bread is quite free from it. When the juice has been carefully expressed, the fecula or flower is washed and dried in the air

without heat, and forms the *Brazilian arrow-root* of commerce; but when dried on hot plates it becomes granular, and forms *tapioca*. An artificial tapioca is made with gum and potato starch: the granules of this are larger, whiter, and more brittle, and more soluble in cold water than genuine tapioca. See STARCH, Fig. 2018.

TAR. See TURPENTINE.

TARTAR, or ARGOL, is an impure tartrate of potash, deposited from grape-juice in the act of fermentation, and forming a crystalline incrustation in wine casks. See WINE.

TARTARIC ACID is the acid of grapes, tamarinds, the pine-apple, and several other fruits in which it occurs in a free state. It also exists as tartar in grapes, tamarinds, mulberries, samphire, &c.; in the roots of wheat and of dandelion, in the berries of sumach, and in the rhubarb plant, the potato, and Iceland moss; it exists in the form of tartrate of lime in squills, madder root, quassia wood, the fruit of *Rhus typhinum*, and the tubercles of *Helianthus tuberosus*. Tartaric acid is prepared by dissolving tartar in hot water, getting rid of the colouring matter of the wine by means of pipe-clay or animal charcoal, and crystallizing. This forms *cream of tartar*, and is used in preparing tartaric acid; for which purpose it is dissolved in boiling water, and powdered chalk added until effervescence ceases, or the liquid is no longer acid. Tartrate of lime and neutral tartrate of potash are formed, and can be separated by filtration, as the tartrate of lime is insoluble. The remaining solution of tartrate of potash is mixed with an excess of chloride of calcium, which throws down all the remaining acid as a lime salt, which is washed and added to the former portion, and the whole is treated with a sufficient quantity of dilute sulphuric acid to form sulphate of lime, which is insoluble, and to set free the tartaric acid. The filtered solution is evaporated to the consistence of syrup, and set aside in a warm place to crystallize. The crystals are often of large size, the figure being that of an oblique rhombic prism more or less modified; their density is about 1·7: they acquire electric polarity by heat, similar to tourmalin: they are colourless, transparent, inodorous, permanent in the air, very soluble in water, and dissolving also in alcohol. The taste is sharply acid; the aqueous solution gradually becomes mouldy by keeping. It is largely employed by the calico printer, for the purpose of evolving chlorine from bleaching powder in the production of white or *discharged* patterns on a coloured ground. [See CALICO PRINTING.] Tartaric acid is much used as a cheap substitute for citric acid in lemonade and effervescent solutions: the crystals contain $C_8H_4O_{10}+2HO$.

Tartrate of potash, $2KO, C_8H_4O_{10}$, may be prepared by neutralizing cream of tartar with chalk, or by saturating it with carbonate of potash: the *neutral tartrate* thus produced is very soluble, whence it is also called *soluble tartar;* it crystallizes in right rhombic prisms, which are permanent in the air; the taste is bitter and saline. The *acid tartrate of potash*, or *cream of tartar*, $KO,HO,C^8H_4O_{10}$, or purified argol, is generally formed when an excess of tartaric acid is added with agitation to a moderately strong solution of a potash salt: it forms small gritty crystals, which dissolve somewhat freely in hot water, but most of the salt separates as the solution cools. This salt has an acid reaction and a sour taste. Exposed to heat in a close vessel it is decomposed; inflammable gas is evolved, and there remains a mixture of finely divided charcoal and pure carbonate of potash; the latter may be separated by means of water. There are two *tartrates of soda;* a neutral salt, $2NaO, C_8H_4O_{10},+4HO$; and an acid salt, $NaO, HO, C_8H_4O_{10}+2HO$. They both crystallize, and are readily soluble in water. The common *saline* or *effervescing draughts* are made by the addition of tartaric acid to bicarbonate of soda. By neutralizing a hot solution of cream of tartar with carbonate of soda, and evaporating to the consistence of a thin syrup, large, transparent, prismatic crystals separate; they consist of *tartrate of potash and soda*;[1] they contain $KO,NaO,C_8H_4O_{10}+10HO$: this salt effloresces slightly in the air, and dissolves in $1\frac{1}{2}$ parts of cold water: it has a mild saline taste, and is purgative. The neutral *tartrate of ammonia* $2NH_4O, C_8H_4O_{10}+2HO$, is a soluble and efflorescent salt. The acid tartrate, $NH_4O,HO,C_8H_4O^{10}$, resembles cream of tartar. There is also a salt corresponding to Rochelle salt, in which ammonia takes the place of soda. The *tartrates of lime, baryta, strontia, magnesia*, and the oxides of most of the metals proper, are insoluble or nearly so in water. *Tartrate of copper* dissolved in a solution of caustic soda is a good test for grape-sugar. [See SUGAR, Sect. I.] In forming tartrate of copper by mixing dilute solutions of tartrate of soda and sulphate of copper, no precipitate is at first produced; but on striking the glass so as to make it vibrate the liquor soon becomes turbid, and if lines be drawn on the glass the precipitate forms upon them. *Tartrate of potash and copper* is formed by boiling hydrated oxide of copper and tartar in water; the solution is used as a water colour, and on boiling it to dryness it forms the pigment known as *Brunswick green*. *Tartrate of lead* forms a very perfect pyrophorus [see LEAD], inflaming on being shaken out into the air. *Tartrate of antimony and potash*, or *tartar emetic*, is prepared by boiling oxide of antimony in a solution of cream of tartar: the hot concentrated solution deposits on cooling crystals of tartar emetic: they dissolve in 15 parts of cold and 3 of boiling water; the taste is metallic, acrid and very disagreeable. The crystals contain $KO,SbO_3,C_8H_4O_{10}+2HO$. A solution of tartaric acid freely dissolves the hydrated peroxide of iron, forming a brown liquid with an acid reaction: on being evaporated at a gentle heat it forms a brown, transparent, glassy substance, very soluble in water and not precipitated by alkalies. The *tartrate* and *ammonia-tartrate of iron* are used in medicine, and are less nauseous than most preparations of iron. The double tartrate of iron and potash

(1) Also called *Rochelle salt*, or, *Sel de Seignette*, from having being first prepared at Rochelle by an apothecary named Seignette.

was formerly used in medicine in the form of balls, under the name of *Globuli Martiales*, *Tartarus Martialis* and *Boules de Nanci:* they were wrapped in a piece of muslin, and suspended in water to form a chalybeate solution.

The action of heat on tartaric acid is remarkable. At about 400° the acid fuses, loses water and passes through three different modifications of *tartralic*, *tartrelic*, and *anhydrous tartaric acid*. Their composition is as follows:—

Ordinary tartaric acid	$C_8H_4O_{10} + 2HO$
Tartralic acid	$2C_8H_4O_{10} + 3HO$
Tartrelic acid	$C_8H_4O_{10} + HO$
Anhydrous tartaric acid	$C_8H_4O_{10}$

Tartralic and tartrelic acids are soluble in water, and form salts with properties different from those of ordinary tartaric acid. The anhydrous acid is an insoluble white powder.

Pyro-acids are formed by the destructive distillation of crystallized tartaric acid. A heavy acid liquid passes over, exhaling a powerful odour of acetic acid; it contains pyrotartaric acid.

A salt called *racemic* or *paratartaric acid* has been found associated with tartaric acid in the grapes cultivated in some parts of the Upper Rhine, and also in the Vosges, in France. It is somewhat less soluble than tartaric acid, and separates first from the solution thereof: its solution precipitates a neutral salt of lime, which is not the case with tartaric acid: in other respects the two acids are almost identical. It is interesting as being the first instance of *isomerism* in organic bodies.

TAWING. See LEATHER, Section VI.

TEA, the name given to a dried herb, the infusion of which forms the most common beverage of the British Isles. Although its introduction into Europe is comparatively recent, it is stated that "tea (*sah*) is mentioned as the usual beverage of the Chinese by Soliman, an Arabian merchant, who wrote an account of his travels in the East about A. D. 850."[1] It does not appear to be mentioned in any European work previous to the entrance of the Jesuit missionaries into China and Japan, about the middle of the sixteenth century. The earliest account is said to be by one Botero, in 1590, who remarks that "the Chinese have an herb out of which they press a delicate juice, which serves them as drink instead of wine."[2] Texeira, a Portuguese, about 1600, saw the dried leaves of tea at Malacca, and Olearius found them in use, in 1633, by the Persians, who obtained them from China by means of the Usbeck Tartars. Anderson states that in Great Britain, in the year 1660, no mention is made in the new book of rates, of tea, coffee, or chocolate, although they are all mentioned in an Act of Parliament of the same year, whereby a duty of eightpence is charged on every gallon of chocolate, sherbet, and tea, made for sale. Pepys refers in his Diary, 25th September, 1661, to "tea, a Chinese drink," of which he had never drunk before. The Dutch East India Company are supposed to have first introduced tea into Europe; and for some years it was brought in small quantities only. In 1664, the East India Company purchased 2 lbs. 2 oz. of tea as a present for the king; and in 1678, they imported 4,713 lbs. of tea, by which time it had begun to form an article in their trade.

Tea must have been used from very early times in China. It has different names in different parts of that extensive country—such as *tcha* or *cha*, and *tha*, whence are derived *tsia*, *the*, and *tea*.

The tea-shrub belongs to the family of the Camellias, and closely resembles them. Though limited in its culture to certain regions of Asia, it is still very extensively cultivated within those regions, and gives employment to a vast number of persons. In China, whence the great supply is obtained, and also in Japan, and in certain parts of India, labour is cheap, and the cultivation and sale of tea can be carried on with a degree of success, which could not probably be obtained in any other part of the world, however favourable the climate to the health of the crop. Two varieties of the plant, known to botanists as *Thea bohea*, and *Thea viridis*, supply the demands of the commercial world. *Thea viridis* abounds in the northern districts of China, where it is cultivated on the fertile slopes of hills, and never in the low lands, and where the whole district appears covered with shrubberies of evergreens, the plantations being made not only in farms specially appointed for the purpose, but in the garden of every peasant. The soil for this crop must be rich, or the shrubs (which are subject to a severe trial in the frequent gathering of their leaves) will soon languish and die.

Fig. 2130.

Two representations of a tea leaf are given in Fig. 2130. They will enable any one to detect the spurious leaves with which tea is often adulterated.

The plant in cultivation in the southern parts of China, and especially about Canton, is the *Thea bohea*, and it was long supposed that from this variety black teas alone could be obtained, while from *Thea viridis* the entire supply of green teas was manufactured. These ideas, however, are entirely mistaken, for the latest and closest investigations prove that the Chinese prepare black or green teas at pleasure from either variety, and that, if necessary, they can make both sorts from the same plant. That they rarely make the two kinds of tea in one district, appears to be merely a matter of convenience. Throughout Che-kiang, and what are known as the green tea districts of the north, the plants are of *Thea viridis*, and black tea is not prepared; in the province of Fokien, and around the Bohea hills black tea alone is prepared; but,

(1) Macpherson's History of European Commerce with India.
(2) Anderson, History of Commerce.

strangely enough, the plants are still of *Thea viridis*, and not *Thea bohea*, although the latter variety derives its name from the mountains of that province. We have this on the authority of Mr. Fortune, a diligent collector of facts concerning the tea districts. Thus, there are green tree plantations on the black tea hills, and from those plants the manufacture of black tea was actively going on at the time of Mr. Fortune's visit.[1] His investigations seem to prove that the black and green teas, manufactured in the northern districts of China, whence the foreign market is chiefly supplied, are all obtained from *Thea viridis;* and that the black and green teas manufactured in the neighbourhood of Canton are all obtained from *Thea bohea*.

Reverting to the northern districts, we find that the first tea-gatherings are in April, and consist of delicate young leaf-buds, which it is very injurious to the trees to remove, but which are considered a choice and valuable gift among friends, and are sent about in small quantities in that way. The showers of spring enable the trees to recover from this early loss of leaves, and in two or three weeks they have brought out a fresh supply. The second gathering, which takes place early in May, is the most important of the season. A third and last gathering supplies only inferior teas. At the time of the May gathering every hill-side is covered in fine weather with groups of persons, gathering the tea-leaves into baskets made of split bamboo. The leaves are stripped off rapidly without any special care, and the young seed vessels go with them, and are dried into a form resembling capers, as we sometimes find them in our tea. When a sufficient quantity of leaves are gathered, they are conveyed to a cottage or barn, where they are not allowed to lie together if designed for green-tea, but are immediately prepared for drying.

The great object in drying is to dispel moisture without losing the aromatic and other properties of the leaf, and by curling up the leaf to enable it the better to retain those properties. The simple means of doing this is as follows:—A number of round,

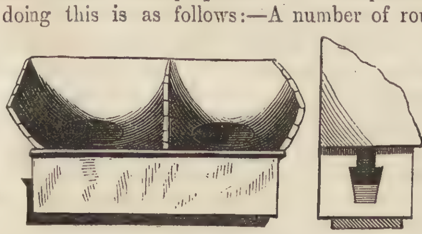


Fig. 2131.

shallow iron pans, Fig. 2131, are built into brick-work and chunam, which encloses a flue, passing along beneath the pans, and having its fireplace at one end, (as shown in the right-hand figure,) and its chimney at the other, or at least a hole to allow the escape of smoke. When the pans are fixed, the brick-work and chunam are carried up a little higher round them, and particularly at the back, widening gradually. When the fire is applied, the upper part of the basins, which is of chunam, gets heated as well as the iron pan, though in a less degree. The drying-pans being low in front, the persons whose duty it is to superintend the drying, can conveniently shake and turn the leaves as they are thrown from the basket into the pan, and keep them in constant motion afterwards. In five minutes the leaves have given out much of their moisture and have become soft and pliable. They are then thrown upon a table made of split bamboo, Fig. 2132, and therefore presenting ridges, over which the leaves are rolled by the hands, as in kneading and rolling dough, until a further quantity of moisture has been pressed out, and a twisting of the leaves effected, which

Fig. 2132.

causes them to occupy much less space than before. Five minutes are spent in this way, and the leaves are then shaken out thinly on a sort of screen, also made of split bamboo, and exposed to the action of the air. Dry and cloudy days are the best for this purpose: in sunny weather the moisture evaporates too rapidly, and the leaves are left crisp and coarse, whereas the desired condition is softness and pliability. A considerable portion of moisture being now got rid of, the leaves are again thrown into the drying-pans, and the second heating commences. Again a slow and steady fire is kept up, and persons stationed at the drying-pans stir and throw up the leaves so that they may be equally dried without getting scorched or burned. The heat of the leaves is now too great to allow of their being handled; they are therefore stirred up with a bamboo brush, and scattered over the smooth chunam-work, down which they roll, and become more and more twisted and curled. This operation is continued for about an hour, when the drying of the tea is completed, and it only remains to pick, sift, and sort the tea into different qualities and prepare it for packing. Tea dried in this manner is of a greenish colour, and excellent quality. It is called *Tsaou-tsing*, or the tea which is *dried in the pan*, in contradistinction to *Hong-tsing*, or that which is dried in baskets over a slow fire of charcoal. The processes are just the same as in the former case up to the period of rolling and exposure to the air; but instead of being put in the drying-pans for the second heating, the Hong-tsing is shaken out into flat baskets, which are placed over tubs containing charcoal and ashes, emitting a very gentle heat, which dries the tea less than by the former method, does not impart so bright a green, and is also a slower process. This tea is not designed for exportation.

The mode of preparing black tea differs in a marked

(1) Three Years' Wanderings in the Northern Provinces of China, &c., by Robert Fortune, Botanical Collector to the Horticultural Society of London. 8vo. London, 1847.

Two Visits to the Tea Countries of China and the British Tea Plantations in the Himalaya, by the same, now in the service of the Hon. East India Company in China. 8vo. London, 1853.

degree from that just described. The freshly gathered leaves are not taken at once to be dried, but are allowed to lie for several hours, perhaps a whole night, spread out upon bamboo mats. They are then tossed about in the hands of the workmen, and thrown into heaps. These are allowed to remain for an hour longer, when they change colour slightly, and become soft and moist. They are then roasted in the pans for five minutes, and rolled on the bamboo table as in the case of green tea. After this they are exposed to the air for three or four hours on bamboo frames in front of the cottages, the workmen turning the leaves, and separating them from each other. They are then put a second time into the roasting-pan for three or four minutes, and taken out and rolled as before. They are now placed an inch thick on sieves, resting in bamboo baskets, over a charcoal fire. In five minutes they are removed for rolling afresh, and then again set over the fire. This heating and rolling may even be repeated a fourth time, the leaves becoming darker and darker in colour. The heat of the fire is now greatly reduced, by covering it up, and the tea is placed thickly in baskets, and set over it until it is completely dry, the workman making an opening with his hand through the centre of the leaves, to allow of the escape of smoke or vapour, and then covering over the whole with a flat basket. The tea is still watched, and occasionally stirred by the workman until it is time to remove it from the fire. The tea is now of its required black colour, a fact easily to be accounted for by the slow processes described, and by the partial fermentation to which it must be subjected while lying in heaps in the fresh state. The colour and active properties of the plant are best preserved by the rapid drying, which produces green tea; hence the greater effect of green tea on the nervous system, and which need not necessarily arise from the means used to heighten the colour by the Chinese.

The fact of the artificial colouring of the teas of commerce is undisputed, and Mr. Fortune tells us that the process may be seen any day during the season, by those who will give themselves the trouble to seek after it; and that the substances used to produce the *bloom* on green teas are Prussian blue and gypsum. These are used in such small quantities as not to be likely to produce any very injurious effect; still they are objectionable adulterants, and are never used by the Chinese to dye the teas for their own consumption. This process of dyeing is sometimes fraudulently carried on to pass off damaged and inferior teas. Sir John Davis was witness to a transaction of this kind which he thus describes:[1]—"Large quantities of black tea, which had been damaged in consequence of the floods of the previous autumn, were drying in baskets with sieve bottoms, placed over pans of charcoal. The dried leaves were then transferred in portions of a few pounds each to a great number of cast-iron pans, imbedded in chunam, or mortar, over furnaces. At each pan stood a workman stirring the tea rapidly round with his hand, having previously added a small quantity of *turmeric* in powder, which of course gave the leaves a yellowish or orange tinge, but they were still to be made green. For this purpose some lumps of a fine blue were produced, together with a white substance in powder, which, from the names given to them by the workmen, as well as their appearance, were known at once to be Prussian blue and gypsum. These were triturated finely together with a small pestle, in such proportion as reduced the dark colour of the blue to a light shade, and a quantity equal to a small tea-spoonful of the powder being added to the yellowish leaves, these were stirred as before over the fire, until the tea had taken the fine bloom colour of hyson, with very much the same scent. To prevent all possibility of error regarding the substances employed, samples of them, together with specimens of the leaves in each stage of the process, were carried away from the place. The tea was then handed in small quantities, on broad shallow baskets, to a number of women and children, who carefully picked out the stalks and coarse or uncurled leaves; and when this had been done, it was passed in succession through sieves of different degrees of fineness. The first sifting produced what was sold as *Hyson-skin*, and the last bore the name of *Young Hyson*. As the party did not see the intermediate step between the picking and sifting, there is reason to believe that the size of the leaves was first reduced by chopping or cutting with shears. If the tea has not highly deleterious qualities, it can only be in consequence of the colouring matter existing in a small proportion to the leaf; and the Chinese seemed quite conscious of the real character of the occupation in which they were engaged; for, on attempting to enter several other places where the same process was going on, the doors were speedily closed upon the party. Indeed, had it not been for the influence of the Hongist who conducted them, there would have been little chance of their seeing as much as they did."

In some communications made to the Chemical Society, Mr. Warrington confirms the above statement as to the nature of the colouring matters employed. These are usually calcined fibrous gypsum, turmeric-root, and Prussian blue; the latter, judging from the specimen sent by Mr. Fortune to the Great Exhibition, "being of a bright pale tint, most likely from admixture with alumina or porcelain clay." Indigo also appears to be occasionally used as a colouring matter. Other writers affirm, in opposition to Sir John Davis, that the colouring is not intended as an adulteration, "but is given to suit the capricious taste of the foreign buyers, who judge of an article used as a drink by the eye instead of the palate." It is affirmed, that the natural yellow colour of green tea would render it unsaleable among the London and American dealers.[2] Mr. B. Seeman, the naturalist of H. M. S. *Herald*, while at Canton collected specimens of teas, and inspected the process. He refers in his

(1) "The Chinese," by Sir John Francis Davis, 1840.

(2) Mr. J. R. Reeves, as quoted by Mr. Warrington

Journal, since published in "Hooker's Journal of Botany, and Kew Garden Miscellany," for January 1852, to the "strange mistake made by Davis, of supposing the whole proceeding of colouring to be an adulteration; and leaves his readers to infer that it is only occasionally done in order to meet the emergency of the demand; while it is now very well known that all the green tea of Canton has assumed that colour by artificial dyeing." One of the great merchants conducted Mr. Seeman over his own and another establishment where the processes of manufacturing the different sorts of tea were going on; everything was conducted openly, without any attempt at concealment. One example is given:—"A quantity of *Bohea Saushung* was thrown into a spherical iron pan, kept hot by means of a fire beneath; these leaves were constantly stirred about until they became thoroughly heated, when the dyes above-mentioned were added, viz. to about 20 lbs. of tea one spoonful of gypsum, one of turmeric, and two, or even three, of Prussian blue. The leaves instantly changed into a bluish green, and having been stirred for a few minutes they were taken out." In spite of all this apparent candour, there appears to have been much falsification in the manufacture, even as witnessed by so intelligent an observer as Mr. Seeman; "for, on submitting these materials to the action of chemical tests, there could be no doubt that they consisted of indigo of a very inferior quality, and leaving a very large proportion of inorganic matter by calcination, and of porcelain clay. It is also curious that the very case selected by Mr. Seeman to illustrate the processes, is the conversion, by means of this facing or glaze, of a low quality of black tea (*Bohea Saushung*), valued at about 4*d.* to 6*d.* the pound, into high quality green teas, valued at from 1*s.* to 1*s.* 6*d.* the pound; but although Mr. Seeman does not allow this to be an adulteration, yet surely he cannot deny that it is a fraud."[1]

We are sorry to add that the falsification of teas is carried on in Great Britain as well as in China—by Christians as well as by Pagans. Mr. Warrington has examined some imported black teas, to which the appearance of green teas was communicated. "The material used as the bodies for this process of manufacture, is a tea called *scented caper;* it is a small closely-rolled black tea, about the size of small *gunpowder*, and when coloured is vended under this latter denomination; the difference in price between the scented caper and this fictitious gunpowder being about 1*s.* a pound—a margin sufficient to induce the fraud. This manufacture has, I understand, been carried on at Manchester, and it was kept as secret as possible; and it was only after considerable trouble that some of my friends succeeded in obtaining two different specimens for me that could be fully depended on as originating in the manufactory. It appears, that it is generally mixed with other tea, so as to deceive the parties testing it. How this manufacture was conducted I am not prepared to say; but some preparation of copper must have been employed, as the presence of that metal is readily detected in the specimens I received. I believe, however, that this sophistication has ceased." Another and more flagrant adulteration is also described by the same excellent chemist. Two samples of tea, a black and a green, were given him by a merchant for examination. The black tea was styled *scented caper;* the green, *gunpowder;* and they are said to be imported into England in small chests called *catty packages.* The teas are apparently closely rolled and very heavy, and they have a fragrant odour. The black tea is in compact granules, like shot, of varying size, and of a fine glossy lustre of a very black hue. The green is also granular and compact, and has a bright pale bluish aspect, with a shade of green, and so highly glazed and faced that the facing rises in clouds of dust when it is agitated or poured from one vessel to another; it even coats the vessel or paper on which it may be poured. The facing was found to be very tenacious, and required soaking in water before it could be removed. In the case of the green tea it consisted of a pale Prussian blue, turmeric, and a very large proportion of sulphate of lime. The facing from the sample of black tea was perfectly black in colour, and consisted of earthy graphite or black lead. During the soaking of these teas they showed no tendency to unroll or expand. One of the samples was treated with hot water without any portion of a leaf being apparent. It increased in size slightly, was disintegrated, and it was found that a large quantity of sand and dirt had subsided, which, on being separated, was found to amount to 15 per cent.; but, as many of the lighter particles had been lost in the washing, a weighed quantity of the sample was carefully calcined until the whole of the carbonaceous matter had been burnt off, and the result was equal to 37·5 per cent. During this operation, also, no expansion or uncurling of the leaf, as is generally to be observed when heat is applied to a genuine tea, was seen; in fact, it was quite evident there was no leaf to uncurl, the whole of the tea being in form of dust, held together by means of gum. The green tea was similar to the black; it yielded 4·55 grains of ash, &c. from 10 grains of the specimen, or 45·5 per cent. A specimen of Java gunpowder yielded 5 per cent. of ash, so that there was in this sample 40·5 per cent. of dirt and sand over and above the weight of ash yielded by the incineration of a genuine tea. These samples consisted of a mixture of tea-dust with dirt and sand, agglutinated into a mass with a gummy matter, most probably manufactured from rice-flour, then formed into granules of the desired size, and lastly dried and coloured. Another imitation of *unglazed* tea yielded 34 per cent. of ash, sand, and dirt. Mr. Warrington states that "about 750,000 lbs. weight of these teas have been imported into this country within the last 18 months, their introduction being quite of modern origin; and I understand that attempts have been made to get them passed through the Customs as *manufactured goods,* and not as teas,—a title which they certainly merit, although it must be evident that the revenue would be defrauded, inasmuch as the consumer would have to buy them as

(1) Quarterly Journal of the Chemical Society, July 1852.

teas from the dealer. It is to be feared, however, that a market for them is found elsewhere. The Chinese, it appears, will not sell them except as teas, and have the candour to specify them as *lie* teas; and if they are mixed with other teas of a low quality, the Chinese merchant gives a certificate stating the proportion of the *lie tea* present with the genuine leaf. This manufacture and mixing is evidently practised to meet the price of the English merchant. In the case of the above samples the black is called by the Chinese *lie flower caper;* the green, *lie gunpowder;* the average value is from 8*d.* to 1*s.* per lb. The brokers have adopted the curious term *gum and dust,* as applied to these lie teas or their mixtures."

Mr. Warrington gives the following results of the careful incineration of a variety of teas; they are valuable as affording an easy method of distinguishing genuine from spurious teas, and in what proportion the one is mixed with the other:—

In 100 parts	grains of ash.
Java Gunpowder Tea gave	5·0
Gunpowder during the East India Company's Charter	6·5
Kemaon Hyson	5·0
Assam Hyson	6·0
Lie Gunpowder, No. 1	45·5
Scented Caper	5·5
Lie flower Caper	37·5
Mixtures containing these lie teas, No. 1	22·5
Ditto ditto No. 2	11·0

We now resume our notice of genuine teas. Black teas include *Bohea, Congou, Souchong,* and *Pekoe.* Bohea is with us the name applied to two kinds of inferior teas; in China it applies to the district where various kinds of black tea are prepared. Congou is a corruption of *Koong-foo,* "labour." It is the next higher kind to bohea, but has latterly given place to some of the better kinds of bohea, which are much stronger. Souchong, or *Seaou-choong,* signifies "small," or "scarce sort," and is the finest of the stronger black teas. Pekoe is mainly composed of young spring-buds, which do not bear much drying; consequently this tea, though fine flavoured, does not keep so well as some other teas, and it is also scarce and dear. Hyson-pekoe, made from green tea-buds, is never brought to England, but is kept for presents in China, as already stated.

Green teas include *Twankey, Hyson-skin, Hyson, Gunpowder,* and *Young Hyson.* Twankey is the lowest in quality, and the leaves are less twisted and rolled than usual, but it is largely imported, and mixed by retailers with the finer descriptions. It is said that three-fourths of our importation of green tea consists of Twankey. Hyson-skin is so named, because *skin* in Chinese means *refuse,* and this tea is the refuse portion of the fine tea called Hyson. The latter name is a corruption of a Chinese word, signifying "flourishing spring," from the season when the leaves are gathered. Gunpowder is a more carefully picked hyson, in which the best rolled and roundest leaves are selected, and give a *granular* appearance, suggesting the name. The Chinese give it a name which means *pearl-tea.* Young Hyson is properly Yu-tsien, "before the rains," because gathered in the early spring. The quantity is so small, that fraud is sometimes employed to imitate the genuine article. Other green teas have been cut up, sifted, and passed off as Young Hyson, so that the fame of this tea has declined. All these varieties of tea are more fully described in Davis's work already quoted, and from whence we have gained the above definitions.

Some years since it was discovered that the tea-plant is indigenous in our Indian territories of Upper Assam, being found there through an extent of country of one month's march from Suddya and Beesa, to the Chinese frontier province of Yunnam. The cultivation of the plant is now carried on in those districts to a very great extent. The capabilities of the valley of the Dhoon are also great. This valley is several hundred miles distant from Assam, and it is expected that all the intervening parts of the Himalayas will be found favourable to the crop. A most favourable account of the tea plantations in the Kumaon and Gurhwal districts of these mountains, was presented to the Directors so long ago as 1847. At that time 176 acres were under cultivation, containing not fewer than 322,579 plants. The crop was thriving in different places over 4 degrees of latitude, and 3 degrees of longitude, and 100,000 acres were then available, and might be readily adapted to the purposes of tea cultivation. Thus there is reason to believe that the period is not very far distant when the produce of the north-west territories of India will compete successfully with that of China in the markets of this kingdom.[1]

The tea-plant is multiplied by seed like the English hawthorn, and in consequence there are many slight varieties among the seedlings, and in certain districts where the climate and soil are favourable, a plant of superior quality is obtained from the same kind of seed which in other quarters may have produced a less favourable result. Hence the importance of procuring young plants and seeds from the best districts, when it is desired to extend the cultivation of this crop. Mr. Fortune was successful in obtaining, during the summer of 1850, a large supply of tea seeds and young plants from some of the most celebrated districts of China, for transmission to India; the latter were carefully planted in Ward's glazed cases; and these, with the collection of seed, reached Calcutta, and finally their destination in the Himalaya tea-plantations, in safety. These plantations, which are in a very thriving condition, can now boast of having a good number of plants from the best districts of the green-tea country and of the black-tea country of China. The tea-seeds had been on a former occasion packed in loose canvas bags, or mixed with dry earth, and put in boxes, or sent in small packages, by post; but none of these plans was successful, owing to the short-lived nature of the seed. At length Mr. Fortune happily thought of sowing the seeds in Ward's cases, and watering them. They germinated during

(1) See also a valuable Report on the Government Tea Plantations in Kumaon and Gurwahl. By William Jameson, Esq. Superintendent of the Botanical Gardens, North-West Provinces, India. Journal of the Agricultural and Horticultural Society of India, vol. vi. Calcutta. 1848.

the voyage, and when they reached their journey's end, were sprouting up as thickly as possible. Mr. Fortune recommends this plan with all other short-lived seeds, and says, "Many attempts are yearly made by persons in Europe to send out seeds of our oaks and chestnuts to distant parts of the world, and these attempts generally end in disappointment. Let them sow the seeds in Ward's cases, and they are almost sure of success. If they are to be sent to a great distance, they should be sowed thinly, not in masses." About 14,000 young tea plants were added to the Himalaya collection by this simple means, and as the same diligent collector also obtained the services of experienced tea manufacturers, and shipped them with their implements to India, he may certainly be said to have done good service in the cause, and to have enhanced the prospects of the trade in India.

The chemical examination of tea has led to much important information respecting this interesting plant. Tea loses about 4 per cent. of water on being dried at 212°, and there appears to be a further loss of water on raising the drying heat to 230°. In addition to the substance of the cells and vessels of the leaves, which in black tea amounts to 27 or 28 per cent., and in green tea to 17 or 18 per cent., tea yields from 4·76 to 5·56 per cent. of ash, which consists of sulphuric acid, phosphoric acid, hydrochloric acid, lime, potash, oxide of iron, and silica. Tea also contains a number of vegetable substances, soluble in different liquids, and common to all vegetables, such as gum, wax, resin, chlorophyl, &c., in addition to which, as partly peculiar to tea, are a volatile oil, tannic acid, and theine.

The following is an analysis, by Mulder, of Chinese and Javanese tea:—

	Chinese.		Javanese.	
	Hyson.	Congou.	Hyson.	Congou.
Volatile oil	0·79	0·60	0·98	0·65
Chlorophyl	2·22	1·84	3·24	1·28
Wax	0.28	0·00	0·32	0·00
Resin	2·22	3·64	1·64	2·44
Gum	8 56	7·28	12·20	11·08
Tannine	17·80	12·88	17·56	14·80
Theine	0·43	0·46	0·60	0·65
Extractive (by means of water and hydrochloric acid)	46·40	40·48	42·04	38·52
Albumine	3·00	2·80	3·64	1·28
Lignine	17·08	28·32	18·20	27·00
	98·73	98·30	100·42	97·70
Salts included in the above	5·56	5·24	4·76	5·36

The *tannic acid* is similar to that which occurs in oak bark, [see Leather,] and in gall-nuts, [see Gall-nut.] According to the above analysis the proportion is much greater in green than in black tea. The *volatile oil* is of a citron yellow colour; it floats on water and readily becomes solid, and by exposure to air is quickly resinified. It tastes powerfully of tea, and when placed on the tongue its influence extends to the throat, and it exerts a powerful action on the nervous system. When tea is distilled with water, this oil separates with it, and the infusion of tea is also impregnated with it. The *theine* consists of $C_8H_{10}N_4O_2$; it neutralizes acids, and is thus allied to the organic bases. It is separated from tea by the following process by Stenhouse:—A decoction of tea is treated with a slight excess of acetate of lead, which throws down the tannine and most of the colouring matters; the decoction is then filtered while hot, and the clear liquor evaporated to dryness. It forms a dark yellowish mass, which is to be well mixed with sand, and sublimed at a moderate heat for 10 or 12 hours. The theine sublimes in beautifully white anhydrous crystals, which are deposited upon the paper diaphragm, which runs across the apparatus.[1] The more slowly the operation is conducted the finer are the crystals. Theine may also be obtained from coffee; the berries are not to be roasted, but only slightly dried, and then ground or pounded, and repeatedly boiled with water until they are exhausted. The filtered decoction should be precipitated while hot by basic acetate of lead; filtered again and boiled with hydrated oxide of lead, which produces a further precipitate, which is separated by filtration. The clear liquor is evaporated to dryness and sublimed, as in the case of the tea extract. A pound of coffee thus yields about 15 grains of theine, not so white as that from tea, but rendered so by a second sublimation. From green Hyson tea 1·05 per cent. of theine was obtained; from black Congou 1·02 per cent.; from black Assam 1·27, and from green Tonkay 0·98 According to Peligot, the proportion of theine in tea is much larger; he obtained from Hyson 2·56 to 3·40 per cent., and from Gunpowder tea 2·20 to 4·10 per cent. When theine is crystallized from water it combines with 2 equivalents, and as a hydrate forms beautiful white, silky needles. At 212° they lose their water of crystallization; they fuse at 353°, and are volatilized without change at 725°, so that theine is not volatilized by the heat employed in drying tea. Theine is readily soluble in hot water, much less so in cold: it is precipitated by tannic acid, the precipitate being insoluble in cold water, but soluble in hot. Theine has no smell, but a bitter taste. According to Peligot, another nitrogenous substance, *caseine*, is contained in tea, but is only dissolved in water when potash is present. He states that 100 parts of Souchong afford—

(1) Mohr's subliming apparatus, Fig. 2133, consists of a shallow cast-iron pan, with a flat bottom and vertical sides, 8 inches in diameter, and 2 inches deep. This contains the substance to be sublimed. A sheet of filtering paper is then stretched over the top, and secured by paste to the sides of the vessel. Over this is fitted a paper cap made of thick packing paper, joined together with paste, and standing about as high as a man's hat; it is secured by means of string. The apparatus thus prepared is placed on a sheet of iron, with a layer of sand intervening, over a slow fire. A modification of this apparatus is shown in Fig. 2134. A funnel-shaped cover of sheet-iron is placed over the top of the pot, and fastened on with linseed-meal lute. This cover has a cylindrical top, about 3 inches in diameter, which fits into a square box of pasteboard or wood. A piece of fine muslin is strained over the mouth of the cylinder, and the box may be provided with a sliding cover at the top for removing the sublimed product. For further particulars see Mohr and Redwood's *Practical Pharmacy*, 8vo. Lond. 1849.

Fig. 2133.

Fig. 2134.

Water	8		
Extract	43	containing	Vol. oil 0·5; Theine 6·0
Exhausted leaves	49	containing	Caseine 14·0
	100		

If this statement be correct, then the most nutritive portion of tea is thrown away in the leaves. Indeed it is evident, from the analysis of tea, that many substances not soluble in water are rejected in the waste leaves. Mulder obtained from 6 specimens of black tea, as the portion extracted by hot water, from 29 to 38 per cent.; and from green tea from 34 to 46 per cent. Peligot obtained from black tea 38 per cent., and from green tea 43 per cent.; and estimated the amount of nitrogen in this soluble portion, solely due to theine, at $4\frac{1}{2}$ per cent. In 100 parts of tea 6 per cent. of theine should be given out in the infusion, but as tea is usually made in domestic economy about one-third of this remains in the leaves. The ordinary infusion often contains the volatile oil, theine combined with tannic acid, gum, and some other extractive matters. If the tea were boiled all the volatile oil would be dissipated; and if the water is not sufficiently hot, little or no theine would be extracted. Hence the practice of making tea in close vessels with boiling water is justified by chemistry: the water must be actually boiling, both for "wetting the tea" and for "filling up the tea-pot," and the tea-pot itself ought to be of such a material as not to suffer loss of heat by radiation: a bright silver tea-pot is the best, and a-black earthenware tea-pot is the worst, that can be used. A strong infusion of tea becomes turbid on cooling, and is covered by a skin which is due to the separation of *tannate of theine.*

Some of the nomadic races of Middle Asia consume tea both as an infusion and as a solid vegetable. They are supplied by the Chinese with what is called *brick-tea,* formed of the old and coarse kinds of tea-leaves, the refuse and stalks of the better kinds, and the leaves of other shrubs, all incorporated with the serum of ox or sheep's blood, and formed into thick 4-sided cakes or bricks. "It supplies these nomadic races with a very portable food, which renders the very worst water of the Steppes drinkable. They are in the habit of rubbing it up with water, and boiling it with the addition of some flour and suet of beef, mutton, or horse (or in case of need a tallow candle) into a kind of broth, which they take with the salt of the Steppes, and, if possible, with ashes or other alkaline salts. The latter are obviously used, though unwittingly, to dissolve the caseine as much as possible."[1]

The rapid extension of tea and coffee among all classes of society in Great Britain, and of coffee on the continent, is a remarkable fact, and can only be accounted for by referring to that wonderful instinct which often takes the place of reason and science, and acts with more effect and precision than either. Much has been written on the folly of poor people spending money upon tea instead of nutritive food; and yet, if Liebig's view be correct, the folly belongs to the writers in question, and not to the purchasers of tea; for, to say nothing of the diminution of inflammatory diseases consequent on its general use, tea proves to the poor a substitute for animal food, and to females, and persons confined by sedentary pursuits, it becomes a substitute for bodily exercise. Liebig says, "We shall never, certainly, be able to discover how men were led to the use of the hot infusion of the leaves of a certain shrub (tea), or of a decoction of certain roasted seeds (coffee). Some cause there must be which would explain how the practice has become a necessary of life to whole nations. But it is still more remarkable, that the beneficial effects of both plants on the health must be ascribed to one and the same substance, the presence of which in two vegetables belonging to different natural families, and the produce of different quarters of the globe, could hardly have presented itself to the boldest imagination. Yet recent researches have shown, in such a manner as to exclude all doubt, that caffeine and theine are in all respects identical. * * * * Without entering minutely into the medical action of caffeine or theine, it will surely appear a most striking fact, even if we were to deny its influence on the process of secretion, that this substance, with the addition of oxygen and the elements of water, can yield taurine, the nitrogenized compound peculiar to bile:—

$$\begin{array}{lcr} \text{1 atom of caffeine or theine} & = & C_8N_2H_5O_2 \\ \text{9 atoms of water} & = & H_9O_9 \\ \text{9 atoms of oxygen} & = & O_9 \\ \hline & & C_8N_2H_{14}O_{20} = \\ \multicolumn{3}{r}{\text{2 atoms of taurine } 2\,(C_4NH_7O_{10})} \end{array}$$

To see how the action of caffeine, asparagine, theobromine, &c. may be explained, we must call to mind that the chief constituent of the bile contains only 3·8 per cent. of nitrogen, of which only the half or 1·9 per cent. belongs to the taurine. Bile contains, in its natural state, water and solid matter in the proportion of 90 parts by weight of the former, to 10 of the latter. If we suppose these 10 parts by weight of solid matter to be choleic-acid, with 3·87 per cent. of nitrogen, then 100 parts of fresh bile will contain 0·171 parts of nitrogen in the shape of taurine. Now this quantity is contained in 0·6 parts of caffeine; or $2\frac{8}{10}$ths grains of caffeine can give to an ounce of bile the nitrogen it contains in the form of taurine. If an infusion of tea contain no more than the $\frac{1}{10}$th of a grain of caffeine, still, if it contribute in point of fact to the formation of bile, the action of even such a quantity cannot be looked upon as a nullity. Neither can it be denied that in the case of an excess of non-azotized food, and a deficiency of motion, which is required to cause the change of matter of the tissues, and thus to yield the nitrogenized product which enters into the composition of the bile; that in such a condition the health may be benefited by the use of compounds which are capable of supplying the place of the nitrogenized product produced in the healthy state of the body, and essential to the production of an important element of respiration. In a chemical sense—and it is this alone which the preceding remarks are intended to show—caffeine or theine, aspa-

(1) Knapp's Chemical Technology, vol. iii. English translation.

ragine, and theobromine are, in virtue of their composition, better adapted to this purpose than all other nitrogenized vegetable principles. The action of these substances in ordinary circumstances is not obvious, but it unquestionably exists. Tea and coffee were originally met with among nations whose diet is chiefly vegetable."

The greater part of South America is supplied with tea from Paraguay, known as *Paraguay-tea.* It is a similar product to the tea of China, and is obtained from a kind of holly, *Ilex Paraguariensis.* It is of a dirty-yellowish colour, a mixture of very small pieces of leaf, with stalks, and part of the stems dried over the fire. Its taste is peculiar, somewhat similar to the inferior kinds of Chinese tea: it is taken as an infusion with sugar, or with lemon-juice. There are several varieties of this tea, some of which are said to produce an unpleasant kind of excitement.

In the year 1850, the quantity of tea imported into the United Kingdom, was 50,512,384 lbs.; in 1851, 71,466,421 lbs.; and in 1852, 66,361,020 lbs. In 1850, the quantity retained for home consumption was 51,172,302 lbs, on which the duty paid amounted to 5,596,961*l.*; in 1851, the quantity retained was 53,949,059 lbs.; and in 1852, 54,724,615 lbs.

The amount of duty on tea has for some years past been charged at the rate of 2*s.* $2\frac{1}{4}$*d.* per lb. By an act passed in the Session of Parliament, 1853, the duty was reduced to 1*s.* 10*d.* per lb., until the 5th April, 1854; after which, until 5th April, 1855, it is to be 1*s.* 6*d.* per lb.; 1*s.* 3*d.* from the last date until 5th April, 1856; and from and after that date the duty is to be 1*s.* per lb.

TEAK. See Woods.

TEASEL. See Wool.

TEETH of WHEELS. See Wheels.

TELEGRAPH, a machine or contrivance for communicating intelligence to a distance, whence the origin of the word from τῆλε distant, and γράφω to write. It has also been called *semaphore,* from σῆμα a sign, and φέρω I bear. In its most extended sense telegraphic communication includes the whole art of making signals, whether by means of special machines, flags, lanterns, rockets, blue lights, beacon fires, &c., or by audible signals, such as are afforded by guns, trumpets, gongs, drums, &c. Whatever be the signal, the party making it, as well as the party for whom it is intended, must have previously arranged a certain meaning or sets of meanings to the signals, however made. In early ages the signals were rude, and the intelligence intended to be conveyed by them was of a very simple character. It is only in comparatively recent times that machines have been arranged for communicating long messages to a distance by means of the semaphore: but that was exposed to the serious inconvenience of not being available by night or in foggy weather. The last contribution to this art is the Electric Telegraph, which is available by night as well as by day, and for precision and rapidity in making the signals, as well as in conveying them, is incomparably superior to all other means for *writing at a distance.* Our article on that subject will convey to the general reader a sufficient knowledge of the details by which such surprising results are accomplished.

The use of beacon fires is very ancient, and is mentioned in Jeremiah vi. 1. It is an obvious mode of conveying information, and is said to be practised by the Bosjesmans, a race of beings very low in intelligence; so also, the Indians of America adopt another very natural method of conveying information from hill to hill, by throwing out their arms with or without staves in them; spreading out their cloaks, holding up skins, &c. While there is abundant evidence to prove that such natural means of telegraphing have been in use from the earliest times, arising in fact from the necessities of man's nature, it is only in comparatively recent times that special machines have been contrived for the purpose. Kircher, Shottus, Kessler, and the Marquis of Worcester, have suggested certain ideas for telegraphic machines, which however do not appear to have been carried into execution, at least in the times of their proposers. The Marquis of Worcester, in his "Century of Inventions," published about 1663, proposes the enigma, "How at a window, as far as the eye can discover black from white, a man may hold discourse with his correspondent without noise made or notice taken." Also "A way to do it by night as well as by day, though as dark as pitch is black." Bishop Wilkins, also, in a work entitled "Mercury, or the Secret and Swift Messenger," after adapting to the English language a proposal for a telegraph by Polybius, gives a plan for conveying messages by night by means of torches; and he also suggests, that in arranging lines of telegraphic communication, the telescope (or as he terms it, in honour of its then recent discoverer "Galileus his perspective"), may be used for making out distant signals.

In the Philosophical Transactions for 1684, Dr. Hooke described a telegraph consisting of signals to be repeated from station to station between the two extremes of the space to be traversed. This plan, which, like the previous proposals, was not put in practice during the author's life-time, has since been repeated and varied many times. It consisted in exposing in succession as many different shaped figures or signs as there are letters in the alphabet. If used by day, they were to consist of squares, circles, triangles, &c. made of wood; if by night, of torches or other lights disposed in a certain order. These figures or lights were to be brought forth from behind a screen s, Fig. 2135, on rods, and exposed to view. The first signal, being made at the terminus, would be simply copied or repeated by the man at the first station as seen by him through a telescope directed to the terminus: having repeated the signal, he would look through another telescope directed to the second station, and when he saw that the signal was correctly repeated there, he would return to the telescope which looked towards the terminus and repeat the second signal, which, in like manner, would be taken up and repeated at all the intermediate stations, until at length, at

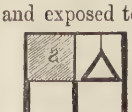


Fig. 2135.

the other terminus all the signals being put together, and representing letters of the alphabet, or numerals, would have an intelligent meaning to persons who had the key; for, of course, it is not to be supposed that the men employed in making and repeating the signals have any more knowledge of their meaning than a postman has of the contents of the letters which he delivers from door to door.

About 20 years after the publication of Hooke's machine, a similar contrivance was produced in France by M. Amontons, in the form of a proposal, or model, at least. The plan was published over Europe, and excited much attention; but there is no evidence of a working telegraph having been erected until 1793 or 1794, when, in a Report by Citizen Barrère to the Convention, Chappe's telegraph, sometimes called the T *telegraph*, from its position when at rest, is recommended. It consists of a beam of wood moveable on a pivot at the top of a post, as in Fig. 2136: at each extremity of this beam is a moveable arm; by which arrangement the beam may be moved to any angle with respect to the vertical post, and the arms into any position with respect to the beam.

Fig. 2136.

In this way as many as 256 signals may be obtained; but as the message was conveyed letter by letter, M. Chappe simplified the working of the instrument by making use of an alphabet of 16 letters only. These, of course, had quite an arbitrary signification, which could be changed at any time for the purpose of secresy or of rendering worthless any former key which might have got into unfriendly hands. A line of such telegraphs was formed, with one terminus at the Louvre in Paris and the other at Lisle, the intervening stations being situated on elevated spots. In this way the Committee of Public Welfare in Paris could communicate with the army in the Low Countries; and Barrère states that the news of the recapture of Lisle reached Paris an hour after the troops of the republic had entered that place. A signal could be repeated from one station to another in 4 seconds, but 16 seconds were allowed for observing the signal and noting it down. It is stated, however, that it was difficult for common men to report the signals correctly.

In 1794, Mr. Lovell Edgeworth invented his *Tellograph*,[1] Fig. 2137, consisting of 4 wedges or cones, moveable on 4 vertical posts, the different positions of which were arranged so as to represent letters or numbers.

Fig. 2137.

In the position shown in Fig. 2137, the 4 wedges represent the number 6103.

In 1795 the advantages of the French T telegraph were much talked of in this country, and many plans were proposed for obtaining similar advantages in Great Britain. The Rev. J. Gamble, Chaplain to the Duke of York, invented a *Shutter Telegraph*, Fig. 2138, consisting of 5 boards placed one above the other, and so arranged, that, by opening one or more, as many signals could be obtained as there are permutations in the number 5.

Fig. 2138.

The same gentleman also invented a *Radiated Telegraph*, Fig. 2139, consisting of 5 wooden arms turning on the top of a vertical post so as to form radii of a semicircle at equal angles of 45°. By making any one or more of these radii coincide with its neighbour, the number and positions of the radii could be greatly varied.

Fig. 2139.

In 1795 the first *Admiralty Telegraph*, Fig. 2140, on the *shutter* principle, was proposed by Lord G. Murray. It was erected over the Admiralty, and was first worked on the 28th January, 1796. By means of a line of such telegraphs between London and Dover, a message could be conveyed from one terminus to the other in 7 minutes.

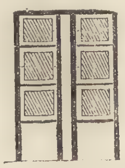


Fig. 2140.

This telegraph was used during the war, and continued in use until 1816, when it was superseded by the semaphore, Fig. 2150. When the boards are turned one quarter round so as to present only their edges to the observer, no signal is intended; but when 1 shutter or more is turned with its broad surface to the next station, a signal is meant. In this way 63 different signals or numbers can be made out of the shutters, which are numbered in the following order,

1 2
3 4
5 6

By presenting the broad face of No. 1 the signal 1 is intended, and this may correspond with a particular letter in the key. No. 2 or No. 3 . . . No. 6 may, in like manner, have its own meaning; then, by keeping No. 1 standing, we may open 2 . 3 . 4 . 5 . 6, and thus get the numbers 12 . 13 . 14 . 15 . 16. By keeping No. 2 standing, the numbers 23 . . . 26 are obtained, and by an extension of the principle, all the numbers contained in the following table are at length obtained:—

1	23	123	234	1234	2345
2	24	124	235	1235	2346
3	25	125	236	1236	2356
4	26	126	245	1245	2456
5	34	134	246	1246	3456
6	35	135	256	1256	12345
12	36	136	345	1345	12346
13	45	145	346	1346	12456
14	46	146	356	1356	13456
15	56	156	456	1456	23456
16					123456

These numbers or signals allow every letter of the alphabet to be indicated, and there still remains a

(1) Mr. Edgeworth claimed to have invented in 1767 a plan for distant communication by employing a common windmill, and arranging the various positions of its arms and sails, so as to represent certain signals. Mr. Edgeworth remarks, on the etymology of the word, that "while *telegraph* is a proper name for a machine which describes at a distance, *telelograph*, or, contractedly, *tellograph*, is a proper name for a machine which describes words at a distance."—*Essay on the Art of Conveying Secret and Swift Intelligence*, published in the Transactions of the Royal Irish Academy, vol. vi.

number of signals with which words or questions in common use may be connected.

In 1794 or 1795, Mr. Garnet proposed to divide a large circle, Fig. 2141, into 24 parts, to represent the letters of the alphabet, across which a moveable radius or arm with a cross was to traverse, and by placing corresponding divisions by means of wires before the object glass of the telescope, the coincidence of the two radii or of the arm would point out the letter intended to be repeated. It was found that this plan was not practicable for long distances.

Fig. 2141.

Fig. 2142. The first French *Semapheric Telegraph* said to have been erected on the palace of the Tuileries in 1796. It consisted of an immense wooden frame with 7 arms; but it was soon abandoned, as all telegraphs must be which aim at prodigious powers.

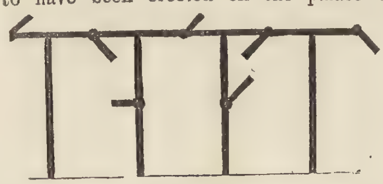


Fig. 2142.

Fig. 2143. Mr. Edgeworth's final plan of the *Tellograph*, 1796.

Fig. 2143.

Fig. 2144. Idea of a *Two-armed Telegraph*, having one arm in the form of a cross, the other in the shape of a sword-cutler's sign, suggested to Mr. Edgeworth in 1796.

Fig. 2144.

Fig. 2145. The French *Coast Telegraph*, called the *Semaphore*, said to have been invented in 1803.

Fig. 2146. Captain (now Major General) Pasley's first *Polygrammatic Telegraph*, invented in 1804, published in 1807.

Fig. 2145.

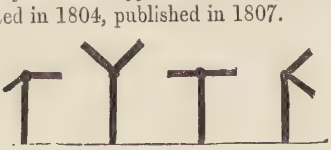


Fig. 2146.

Fig. 2147. Lieut. Col. Macdonald's *Shutter Telegraph*, published in 1808. Fig. 2148, is a shutter telegraph proposed in India by Captain Swiney.

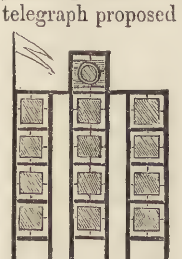


Fig. 2147.

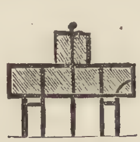


Fig. 2148.

Fig. 2149. Captain Pasley's second *Polygrammatic Telegraph*, published in 1810.

Fig. 2150. Rear-Admiral Sir Home Popham's *Land Semaphore*, adopted in 1816 by the Admiralty instead of the shutter telegraph. This telegraph was a great improvement upon the preceding ones, in simplicity of construction and in the mode of working the arms. The vertical post is a hollow hexagonal mast, turning on a pivot at its foot, and in a collar where it passes through the roof of the cabin or telegraph observatory, so that its arms may be made to work in any plane. The arms are counterpoised by a mass of lead at the head of each, so that they will remain in any position into which they are moved, and when out of use they fall into slots in the post, so as to be quite out of sight. The arms are moved by means of two winch handles situated in the observatory near the base of the mast. These handles give motion to two small spur wheels on vertical axes, which gear into two similar wheels on horizontal axes, and these act upon upright shafts or rods passing up the interior of the hollow post: at the upper extremities of these rods, which are held in place by bearings, are endless screws working into spur wheels attached to the axes of the arms, by which means the arms may be set in motion. In order to guide the signal-man in making or repeating a signal, similar toothed wheels and indices moving over graduated arcs are attached near the bottom of the vertical rods, so that whatever signal is made on the lower index is faithfully repeated by the arm above.

Fig. 2149.

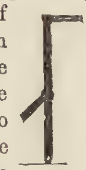


Fig. 2150.

Fig. 2151, represents Sir Home Popham's *Ship Semaphore*, also established in 1816.

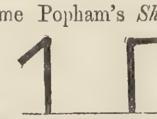


Fig. 2151.

Major-General Pasley has bestowed much attention on the construction and working of telegraphs. He states[1] that although he had long regarded Popham's arrangements with satisfaction, he was led to the conclusion that the use of two separate pivots in the land semaphore and of two posts in the ship semaphore was an unnecessary complication; and that considering simplicity in construction to be of more importance than the power of making many changes, he had abandoned the polygrammatic principle, and adopted what he terms the *Universal Telegraph* for day and night signals. For day signals this consists of an upright post, Fig. 2152, with two movable arms fixed near the top by a pivot, and a mark called the *indicator* on one side of it. Each arm can exhibit the 7 positions 1 . . . . . 7, Fig. 2153, besides its quiescent position called *the stop*, in which it points vertically downwards and is concealed by the post. In Fig. 2153, the sign 17 is shown, the other positions of the arms being indicated by dotted lines. The indicator serves to distinguish the low numbers 1, 2, and 3, from the

Fig. 2152.

Fig 2153.

(1) " Description of the Universal Telegraph for Day and Night Signals." By C.W. Pasley. Lieut-Col. Royal Engineers, and F.R S. London. 1823.

high numbers 7, 6, and 5. This distinction is of importance, for it was found that in the use of Sir Home Popham's ship semaphores ambiguity sometimes arose from the signals being seen in reverse, in which case one number or sign would be mistaken for another. By the addition of the indicator it was always evident at a glance on which side the numerals commenced, whether the semaphore were seen on the windward or the leeward side of the ship. The signals given by this telegraph are enumerated in the following table,—

1	7	17	34	47
2	12	23	35	56
3	13	24	36	57
4	14	25	37	67
5	15	26	45	
6	16	27	46	

Fig. 2154 represents the telegraph fitted up for night signals. It is shown on a larger scale in Fig. 2155.

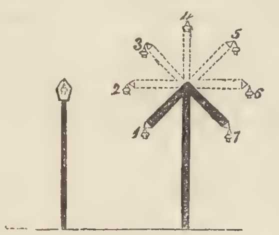


Fig. 2154.

One lantern C, called the *central light*, is fixed to the same pivot on which the arms move. Two other lanterns are attached to the extremities of the arms. A fourth lantern L, used as an indicator, is fixed on the same horizontal level with the central light, at a distance from it equal to twice the length of one arm, and nearly in the same plane in which the arms revolve. With these 2 fixed and 2 moveable lights, 28 signs can be made. As the indicator is merely a mark which when once seen requires no further attention, and the central light by night and the post by day being merely guides to the eye, the signs of this telegraph are really composed of the combinations of only two moveable lights by night, which renders this telegraph very simple. The arm and the indicator for the day signals are of wood framed and panelled: in hot climates plates of copper may be used for the panels. The indicator plays in a mortise cut in the upper part of the post, and is let down into its horizontal and raised into its vertical position by a rope and pulley. The arms are fixed externally one on each side of the post, and exactly counterpoised by means of light frames of open ironwork which are not seen by day at a short distance. This counterpoising is necessary to allow the arms to remain in any given position without being held by the hand or stopped by some mechanical contrivance. Motion is given to the arms by means of an endless chain passing round and acting upon a couple of pulleys, one of which is fixed to the arm itself and turns upon the same pivot; the other moves upon a pivot fixed to the lower part of the post. The chain consists alternately of single and double plates, of an oblong form, and riveted together at the ends on the principle of a watch chain. The pulleys are furnished with projecting teeth or studs, which engage the double or open parts of the chain. In this way each arm follows accurately the movements of an index or lever below, attached to the lower pulley, which has a dial plate opposite to it marked on the post for the guidance of the signal man. On board ship a rope is sometimes used instead of the chain. At the end of each arm two light pieces of iron meet in an angle of 45°, forming an open triangle, to the vertex of which the moveable lantern L is attached by means of a pin. A cylindrical counterweight W is also fixed to the end of the iron counterpoise. The lanterns and weights are fixed at dusk and removed by daylight, so that at permanent stations the roof of the signal-house over which the telegraph stands has a small flat terrace accessible by a ladder or staircase. In the intermediate stations two lanterns are required for the centre light, one on each side of the post, as in Fig. 2155, in which C C are the central lanterns, L L the moveable ones, and W W the counterpoise weights. The indicator light may be fixed to a separate post as in Fig. 2154, or be attached to a rod *r* strengthened by a

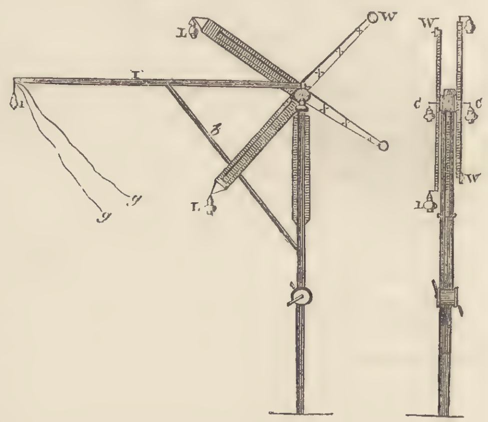


Fig. 2155.

brace *b*, and guy ropes *g g*, as in Fig. 2155. For ships or for field service the length of the telegraphic arm does not exceed 5 or 6 feet; but at permanent stations on shore they may be much longer. Lieut.-Col. Pasley's calculation is that they should be about 1 foot per mile of the distance between any 2 stations, in order to be distinguished by a common portable telescope of moderate power. This length is computed from the centre of motion to the end of the arm. The width of the arm need not exceed $\frac{2}{13}$ths of its length, and not less than $\frac{1}{7}$th or $\frac{1}{8}$th. The indicator for the day signals should be of the same width, but only $\frac{4}{5}$ths of the arm in length. The arms should be painted black, and placed so as to be seen without any background; but if a background be unavoidable, the arms should be painted so as to contrast with it; and should the background vary greatly at different periods of the day the arms should be painted in bold black and white chequers. The lamps used on shore are square like those used in mail-coaches, having the two glass sides opposite to each other, so as to show the light in 2 directions only: but for sea service the *globe-lamp* is best; the light shines in all directions through a strong globular glass, in which are fitted a copper top and bottom pierced with air-holes.

Much discussion was formerly held respecting the

comparative merits of *shutters* and *arms*. Colonel Macdonald, who has published a very voluminous work on "Telegraphic Communication,"[1] writes strongly in favour of the shutter principle, and asserts that "the semaphore arm of proper dimensions is not to be seen in clear weather so well as the common sized boards, and in cloudy weather by no means so well," and that "for this climate the boarded telegraph is in all respects more advantageous." To this statement Mr. Gamble replies as follows:—"It is a theorem in optics that the apparent magnitude of an object varies nearly in the inverse ratio of its distance. Hence it follows that the larger its dimensions, to the greater distance will it be visible. But the nature of our atmosphere, even in its most transparent state, is such as to render any calculation grounded on this principle extremely erroneous; and in general its density so obstructs, and its refracting powers cause such confusion in the rays issuing from those surfaces which are not placed sufficiently distant to be distinct, that their image falling upon the retina is frequently so ill defined as to render it difficult to determine either their figure or position; for which reasons, that which I shall term *insulation* is generally a quality more requisite to give distinctness to an object, than magnitude of superficial dimensions. An example of this distinctness arising from insulation cannot be more readily obtained than by taking a page of printed paper and fixing the eye on some particular letter, as I; then retiring from it, the letter will be so confused with the surrounding ones as not to be easily distinguished. But if the same letter I be printed on a plain sheet of paper, standing by itself, or *insulated*, the eye will then not only discern it at a much greater distance, but the image falling single and unencumbered upon the retina, we shall be able to determine whether it be inclined to the right or to the left, or whether it be placed horizontally on the paper." Experience has abundantly proved that the arms of the semaphore were seen with much greater distinctness than the shutters of the telegraph. Indeed, in order to test the comparative merits of the two, when the shutter telegraph was superseded by the semaphore, the former was left standing for a whole winter on the same hill at Nunhead with the new semaphore. The result was that the semaphore was often visible when the shutters were so much enveloped in fog or mist as to render it impossible to distinguish which particular shutter was closed or opened. It also appears, from a journal kept by the officer at the station, that in the course of the winter the days on which the semaphore was visible exceeded those on which the shutters could be seen by fully one third.

The six-shutter telegraph is capable of producing a larger number of combinations than the two-armed semaphore, without using the *stop*-signal, or that which separates one word or one sentence from another. But the Admiralty semaphore had abundant powers, as is proved by the following table:—

No. of Signal by 1 and 2 arms.	Signification.	No. of Signal by 1 and 2 arms.	Signification.	No. of Signal by 1 and 2 arms.	Signification.
1	1	15	G	43	X
2	2	16	H	44	Y
3	3	21	I	45	Z
4	4	22	K	46	
5	5	23	L	51	
6	6	24	M	52	
I	A	25	N	53	
2	B	26	O	54	
3	C	31	P	55	
4	D	32	Qu	56	
5	E	33	R	61	
6	F	34	S	62	
11	7	35	T	63	
12	8	36	U	64	
13	9	41	V	65	
14	0	42	W	66	

making in all 48 separate and distinct signals.

The reader who is curious in telegraphs will find a large number, which we have not even mentioned by name, described in Col. Macdonald's work, and also in many of the volumes of the "Transactions of the Society of Arts," especially vols. xxvi. xxxiv. xxxv. and xxxvi.

In the navy, flags of various forms and colours have been long used for conveying signals from ship to ship. It is said that Lord Howe proposed to mark the signal flags with numbers which should correspond with words or sentences previously agreed on. In 1798 the Admiralty issued a signal-book on this plan: it contained about 400 sentences expressive of the common operations of the fleet; but if a message had to be conveyed which was not found in the book, the ship proposing to send the message had to signal "for a boat," or "a boat from each ship," in order to convey it. This defect was remedied by the proposal of Sir Home Popham, to make the flag-signals represent the letters of the alphabet, as well as words and sentences in connexion with the numbers. His other proposal, also adopted, was to cut the signal-flags "so that the selvages of the buntin may be brought on the outer edges of the flags and the gorings in the centre; by which means the outer edge is susceptible of the least air of wind, and when the flag blows out, the gorings assist in keeping it out; whereas the old flags had a hem on the outside which rendered them difficult to move without a fresh breeze, especially in damp and rainy weather, as the hem then became heavy." The number of flags, &c. required for making signals in Sir Home Popham's *Code* is 9 flags, 5 cornettes, 5 triangles, and 5 pendants. Sir John Barrow objects, that with such a number it is next to impossible, in calm weather, to make out the figure and colour of the flags; and equally so when expanded by the wind if the situation of the observer be such that only the edge is presented to the eye. He prefers Popham's sea-telegraph, Fig. 2151, or Pasley's Universal Telegraph, Fig. 2155.

The numerical system with flags, &c. is not difficult. Nine differently coloured or variegated flags represent the numerals 1 . . . . 9; there is also a separate flag for 0, and another called a *substitute*, for

(1) "A Treatise explanatory of a new system of Naval, Military, and Political Telegraphic Communication, &c." By John Macdonald, Esq. F.R.S. late Lieut.-Col. and Engineer. 8vo. London, 1817. The work is accompanied by a copious Telegraphic Dictionary.

repeating any flag, under which it is hoisted, should the same figure occur twice in the number to be expressed: a pendant is also sometimes used as a substitute for the top figure. In this way, by the use of 11 different flags and a pendant, any number from 1 to 999 can be expressed without displaying more than 3 flags, or 2 flags and a pendant at one time.

The flags, &c. should be of the brightest colours, and present the strongest contrasts. When ships are at considerable distances apart, or in the morning or evening, or on a dark day, it is not easy to distinguish one full colour from another, all the colours approaching black in appearance. At the distance of a very few miles scarcely any full colours, except a scarlet and a blue, can be distinguished. Red, blue, yellow, and white can be seen at greater distances than any others, and are therefore the colours used as signals. But even these sometimes occasion difficulties; the yellow being confounded with a dirty white, and the blue with red. In combining these colours to obtain variety, stripes, spots, and chequers are used, the opposition of the combined colours being as strong as possible, and the stripes, &c. not less than 1-third the breadth of the flag. Red should never be striped or spotted with blue. See LIGHT.

Attempts have been made of late years to introduce a uniform code of signals among merchant ships, by which they may readily communicate at sea, or with the coast stations. An Association for the purpose, under the superintendence of Mr. B. L. Watson, was established some years ago, and the Lords of the Admiralty have ordered that Mr. Watson's signal-books shall be supplied to all the vessels of the Royal Navy, in order that they may have the means of readily signalling any merchant ship at sea that is in possession of this plan. The whole code consists of 13 flags, by which any message can be conveyed from one vessel to another, or between a vessel at sea and one of the coast stations established by the Association on prominent points about Great Britain. In connexion with these coast stations there were lines of semaphores (now superseded by the more efficient electric-telegraph) from the Downs to London, from Holyhead to Liverpool, and from the Spurn to Hull; and from such stations communications are transmitted to a central office in London, and also to the owners or consignees of vessels entered in the telegraph list; for which privilege an annual subscription of 20*s.* is charged for each vessel. So also any message from the owners of a vessel as to change of destination, &c., can be communicated from any station within sight of which the ship may pass.

The construction of a "Telegraphic Dictionary" was at one time a favourite employment with persons engaged either in inventing or making frequent use of telegraphs; and as the inventors of knick-knacks (and there is a good deal of knick-knackery in this subject) are numerous, so are the books on the subject. One of these dictionaries extends to 140,000 numbers, with a separate sentence to each number. Another occupies 120 pages, with 3 columns in a page, and 60 sentences in each column: in a large number of pages each sentence begins with the personal pronoun "He," 20 pages with "If," and so on. Spelling the sentences would be much more certain as to the meaning, and in many cases more expeditious. The communications should be in an abbreviated form, and in such cases spelling is to be preferred. Thus the sentence, "Order the Agamemnon out of harbour, and direct her to proceed to Spithead," will be sufficiently expressed by "Agmemn. to Spthed." It is also of importance to condense the point or important part of the communication into the former part of the sentence, so that no serious mistake may arise should foggy weather intercept the message. For example, during the Peninsular War a telegraphic message was sent from Plymouth to London: the words "Wellington defeated—" were received, when a fog prevented further communication, thus leaving the government for some hours under the terrible impression that our great general had sustained a defeat. Whereas, had the message commenced with the words "French defeated at" &c., the truth would have been more concisely expressed, and the fog would have bisected the message with less inconvenience than when it was put in the form, "Wellington defeated the French at," &c. Sir John Barrow, who relates this anecdote in the *Encyclopædia Britannica*, article NAVY, says, "In clear weather, the rapidity of working single signals, the short compass within which any message may be condensed, the impossibility of committing any mistake that cannot be immediately rectified, more than compensate for the difference of a few minutes which the use of sentences may probably save. In cloudy or foggy weather the latter method will always be liable to mistake. If experience may be assumed as a guide, the practice of the Admiralty of spelling all sentences for the last 30 years, must decide in favour of that system."

Before the introduction of the electric telegraph the semaphore was worked with remarkable facility and despatch. A short message could be conveyed between Portsmouth and the Admiralty in 1½ minute, but a special message, which was always sent at a stated hour each day, and for which therefore all parties were on the look out, has been sent through in 31 seconds. The signal-men, during clear weather, were always on the look out, and such was the facility which they had acquired from long use in reading off the signals, that even in hazy weather, when to an unaccustomed eye the signal would be invisible or too indistinct to be decyphered, the signal-man would read it with facility. Foggy weather however greatly interfered with the transit, so that at times the transmission of signals along the entire line was impracticable for hours or even days together. In order to avoid as far as possible any inconvenience from this delay, there was a rule that if any station in the line, through fog, inattention, or any other accident, should be unable, within two minutes, to pass the signals it had received onward to its next adjacent station, then this last station in the perfect portion of line was to receive the whole of the message, acknowledge its receipt by the return signal, and send on the signals

either by post, express, or semaphore, as might be found advisable, to its final destination.

Signals are also made at sea by means of guns, rockets, blue-lights, &c. Gun-signals are distinguished by the time which is allowed to elapse between the discharges; and thus the signals may be *slow*, *moderate*, and *quick*. *Half-minute* guns are the slowest among single signals. *Quarter-minute* guns admit of two subdivisions. With well-trained gunners intervals of 15 or 12 seconds may be taken for slow firing, 8 or 10 seconds for moderate, and 4 or 5 seconds for quick firing. A small number of firings, varied in this way as to time, will give a large number of signals. Thus 5 guns with the variation of only *quick* and *moderate* will give 20 signals. Here, as in flag signals, the most simple must be appropriated to the most important orders.

The signals used on railways require some notice in this place, if it were only to extend the knowledge of the important fact, that numbers of persons are incapable of distinguishing colours, or are, in fact, afflicted with what is called *colour-blindness*. This subject has been partially investigated at different times, but it has lately been very fully inquired into by Dr. George Wilson of Edinburgh, from whom we have received the following communication:[1]—

"The colours selected to distinguish the danger-signals on our railways, and, if I mistake not, those of other countries also, are red and green, which are used by day on painted plates of metal and flags of linen or cotton, and by night on glass illuminated from behind by oil or gas-lights. In using the colours in question, it is plainly taken for granted that the large majority of mankind are strongly impressed by them, and easily detect the difference between them; and it is believed that no inquiry is instituted by railway-companies into the colour-vision of their servants. It is certain, however, that at present the great mass of the community of all ranks receive no education in the discrimination of colours, and are not, at least in the case of males, acquainted with the names of more than a very few; whilst in the humbler classes an examination of more than 700 males has led to the conclusion that they do not familiarly name more than seven colours, namely, red, blue, yellow, green, brown, white, and black; even such important names as orange and purple being never employed, and no substitutes being used for them.

"Such an ignorance of names, although not necessarily implying an ignorance of colours equally great, yet points to an habitual indifference to the distinctions between colours, on the part of the community at large, which shows how cautiously these should be had recourse to as a means of arresting the attention of unpractised eyes.

"But a far more important source of danger from the employment of coloured signals, lies in the fact that a considerable number of persons are born with an incurable defective perception of colour, and are thereby incapacitated from distinguishing between certain colours. *Colour-blindness*, as this defective perception is best named, occurs in males, (in whom it is greatly more common than in females,) to an extent which is not generally suspected or credited. Provost found 1 male in 20 more or less colour-blind, Seebeck found 5 in 40. Professor Kelland found 3 extreme cases in 150 students, and I found 2 in 120, of whom, however, only 80 were specially examined. I have recently, with the assistance of two friends, examined the troops in garrison at Edinburgh, and among 737 men, including 6 officers, I found 53 colour-blind, or nearly 1 in 14. Of these, 11 confounded green with scarlet, 2 light-green with pink, 16 dark-green with brown, 20 green with blue, 1 pink with light-blue, 1 pink with yellow, and 2 yellow with purple, but only to a slight extent. The men were examined by daylight, and one by one: but the examination of so many persons singly, although spread over ten days, was necessarily rapid, and several cases were doubtless overlooked.

"Setting aside the colours not used in railway-signals, and disregarding, as of minor importance, the confusion of green with blue, it appears, that among 757 healthy there were 29, or 1 in 25, who confounded green with scarlet, or pink, or brown; of whom 11, or 1 in 67, could not distinguish a red from a green danger-signal. Prof. Kelland's 3 cases were equally severe, so that 1 in 50, according to his statements, could not be signal-men; and among my examined students of last year there were 2 in 80. During the last nine months I have become acquainted with nearly 50 persons who cannot distinguish red from green; and altogether, the present state of our knowledge warrants the conclusion that 1 in 50 of the male population is liable to confound red with green; but I shall immediately show that the proportion of the community who cannot be safely trusted with the present coloured railway-signals is probably much larger.

"It is a remarkable fact, that the subjects of this affection seldom occur singly in a family, and that there are often six persons within two generations, fathers, uncles, sons, nephews, cousins, as the case may be, all more or less colour-blind. Among the soldiers whom I examined, two of the cases, officers, are brothers, but I had no means of learning anything concerning the relatives of the remaining cases. It seems, however, important to draw attention to the fact, that my numbers, or any others obtained in a similar way, under-estimate the number of colour-blind persons in the community, since many, perhaps the majority of these, belong to a group of relations similarly affected.

"The following conclusions are founded on my own observations, and on the voluntary confessions of trustworthy colour-blind persons; but it is believed that they are quite in harmony with the observations of preceding writers on colour-blindness.

"1. The colours least liable to mistake by the colour-blind are yellow and blue.

(1) Those who desire to extend their knowledge on this subject, cannot do better than study Dr. Wilson's highly interesting paper in the "Monthly Journal of Medical Science," Edinburgh. The number for November, 1853, contains the first part of this paper.

"These when pure and full, and well illuminated, are generally perfectly distinguished.

"2. The colours most liable to confusion by the colour-blind are as follows.

"Bright red, scarlet, and crimson, are confounded with bright green, and occasionally with black; dark red, russet, and brown, with olive and dark green; purple in all its shades, crimson, lilac, lavender, and violet, with blue. Pink, with pale yellow, with light blue, and more rarely with light green. Blue with green.

"3. In extreme cases the confusion of all those colours occurs in a single person; in less severe cases it is limited to two colours, but in the great majority four colours are concerned.

"4. Red and green being the most important colours in reference to Railway-signals, the following points are of special importance in connexion with them:—

"1. Some of those who confound red and green with each other, do so in full sunshine, both by transmitted and reflected light, however near the coloured object be to the eye.

"2. It is more common, however, to find that there is a certain though not constant power of distinguishing between the colours in question, but this power diminishes with great rapidity when they are removed to a distance from the eye, so that a separation of a few feet or a few yards, according to the severity of the cases, abolishes all sense of distinction between red and green. Many of the colour-blind have first become aware of their defect by discovering their inability to distinguish red flowers and fruit from the surrounding green leaves, unless when close to them. It is needless, therefore, to urge that in testing the qualifications of a railway servant to discern coloured signals, his ability to distinguish between red and green *near the eye* is not a sufficient criterion of his freedom from colour-blindness, which must further be tried by removing the signals to as great a distance from him, as they require to be seen from, on occasions of danger.

"3. Those who confound bright red and green at a distance from the eye, are almost invariably found to confound dark red with dark green although close to the eye; and as the coloured day-signals, especially the flags, which alone are available in some of the most pressing emergencies, soon tarnish and darken, the effect of time is to change light reds and greens into much darker shades, and thereby continually to diminish the distance (small at the best,) at which the two signals can be distinguished from each other by a colour-blind observer. It is thus desirable on railways to ascertain to what extent the darkening of colour-signals renders them undistinguishable or obscure to those who can discern them when new and bright.

"4. Many persons are found who mistake dark red and brown for olive and dark green, who do not *appear* on a cursory examination to mistake the brighter shades of red and green; but all such persons are to be regarded with suspicion, as presenting at least the lower degree of colour-blindness in reference to red and green, and as likely to fail in seeing the signals at present in use, at distances where those with normal vision could easily discern them. Now in the Edinburgh garrison there was nearly one man in 40 who mistook dark green and brown, in addition to those who mistook bright green and red, so that the proportion of those in the community who are colour-blind to a degree that makes it hazardous to employ them as signal-men, is probably double what it appears to be, when we reckon as such only those who confound the brightest shades of red and green.

"5. It is a remarkable fact, that many of those who cannot distinguish red from green by day-light, can do so by gas or candle-light; so that this general conclusion may be drawn, that *as far as mere colour* is concerned, the present night signals are safer than the day ones. But it must not be inferred from this that they are *safe*, or that those who are colour-blind by day see normally by night. They see the doubtful colours better, but still badly.

"6. There is in many of those who confound red with green, a positive insensibility of the retina to red, so that in twilight they confound red with black. Thus several distinguished foxhunters are known to me, who cannot tell the black coats from the red in a hunting field in twilight, or at a short distance in day-light. Such persons would not merely confound one signal with another, but frequently not see a red one at all.

"If then the present system of signals on railways be retained, a most strict investigation of the servants should be made; but it seems much safer to dispense with colour by day-light except as an auxiliary, and to trust to the shape and motion of large arms.

"The great difficulty is with the hand signals, especially if 3 signals are to be shown, for no colour-blind person can see three primary colours, and yellow is liable to confusion with white when it is tarnished. For a two-colour system, white and black would be the best throughout the day; and blue and white by night. For pressing emergencies hand lamps are much too small. I greatly approve of a suggestion in the *Times*, that signal lights with red fire or green fire should be in the possession of Guards, for such occasions as those which led to the recent accident near Dublin.

"It is vain to expect, as is urged in the *Times*, that an engine driver who had been gazing at an immense fire, should see a small red lamp.

"But I cannot enter into a question so large and so difficult as that of the best system of signals on Railways."

TELESCOPE. See LIGHT—LENS.

TELLURIUM, Te64, a rare metal, or semi-metal, (named from *tellus*, the earth,) found in a few scarce minerals associated with silver, lead, and bismuth, apparently replacing sulphur. Tellurium has the colour and lustre of silver, and by fusing and slow cooling it exhibits rhombohedral crystals: it is brittle, a comparatively bad conducter of heat and electricity: its density is 6·26, and it fuses at a little below red-heat. It burns when heated in the air, and forms

tellurous acid, TeO_2. There is also *telluric* acid, TeO_3, two chlorides, and a hydruret, resembling sulphuretted hydrogen.

TEMPERATURE. See HEAT—THERMOMETER.

TEMPERING. See STEEL—ANNEALING—SAW, &c.

TEMPLATE or TEMPLET, a pattern plate for the formation by filing or otherwise of curved works. They are useful in cases where the works are wanted in great numbers and of exactly the same form, and in various works that are required to be truly circular, but do not admit of being finished in the lathe. Templates are often formed of hardened steel. They are also much used for setting out and producing series of holes in some kinds of work where exactness is required.

TENACITY. See STRENGTH OF MATERIALS—METAL, Fig. 1439.

TENON AND MORTISE. See CARPENTRY.

TENSION. See STRENGTH OF MATERIALS—ELASTICITY—METAL.

TERRA COTTA, or *baked clay*, a term applied to certain architectural decorations, figures, vases, &c., modelled or cast in a paste composed of a pure clay and a fine grained colourless sand or calcined flints, together with pulverized potsherds or crushed pottery. The article is then slowly dried in the air, and fired to the hardness of stone in a kiln. The clay should resemble that used for making pipes, [see POTTERY and PORCELAIN, Sect. IV.] and should contain little or no iron. The true terra cotta of the ancients was less baked and less durable than that of the moderns, and was indeed little more than sun-baked clay of considerable purity. Some of the architectural ornaments in terra cotta in the Great Exhibition attracted considerable notice. Messrs. Willock & Co. of Manchester exhibited a complete model of a decorated Gothic church in terra cotta, besides a Corinthian capital, a chimney-piece painted in imitation of oak, with the slab in stone, a flower-stand, a piece of Gothic tracery, and other smaller articles, the cost being stated to be from 50 to 75 per cent. below the price of carved stone-work. Mr. Blanchard also exhibited a portion of a Gothic pinnacle, a capital, &c. of good colour and well-executed details. The material is described as being a composition of the best white pipe-clay, crushed pottery-ware, calcined flint, flour-glass, and white sand, all well amalgamated and burnt at a high temperature. [See STONE, ARTIFICIAL.] The composition requires to be very homogeneous, on account of the great shrinking of the articles in the drying and firing.

The following passage occurs in the Jury Report, Class XXVIII. "The Jury recognise the importance of introducing a material so useful and so economical in many cases, especially where the absence of durable stone interferes with the construction of public buildings. A well made terra cotta may be regarded as almost indestructible by ordinary exposure, and although in colour it is generally inferior to good stone, and the parts are liable to warp in burning, yet for some kinds of ornament, and for many practical purposes, the result is everything that is needed."

TERRA DE SIENA, a brown ferruginous ochre, used in painting. See OCHRE.

TESTS are those substances in solution, or in the gaseous form, which are used in chemistry to detect the presence of other bodies also in solution; which they do by forming insoluble precipitates, by changing colour, or by certain other characteristics well known to the practical chemist. Thus a few drops of a solution of carbonate or acetate of barytes added to a solution containing sulphuric acid produces a dense insoluble precipitate of sulphate of barytes. Now, as the carbonate or acetate of barytes does not produce this effect with any other acid, the formation of such a precipitate is a certain test of the presence of sulphuric acid. So also the presence of silver in solution is made evident on the addition of muriatic acid, by the formation of a white curdy precipitate of chloride of silver: lead is detected by sulphuretted hydrogen; iron by solution of galls; the presence of a free acid by litmus paper, which is reddened, and of a free alkali by turmeric paper, which is turned to a reddish brown; or the litmus paper, reddened by an acid and restored to its original blue colour, also indicates the presence of an alkali. These, and a thousand similar cases, which at first view rank only as individual facts, requiring a separate memory for each, are so important in their application and in the progress of chemistry, as to take rank with scientific principles of great breadth and generality. Minute directions as to Tests and Testing are given in Faraday's "Chemical Manipulation," and also in Bowman's "Introduction to Practical Chemistry."

TEXTILE FABRICS. See WEAVING.

THEINE. See TEA.

THEODOLITE. This is the most important instrument used by surveyors for taking horizontal and vertical angles, since by its construction it is not necessary in either case that the objects should be in the same horizontal or vertical planes. The simplest form of the theodolite is a divided circle, which is to be set parallel with the horizon, and a telescope which has so much motion in a vertical plane as to enable the observer to view any required object above or below the horizon. Although the instrument is of comparatively recent date, the origin of its name is not well known. Up to the latter half of the last century, the quadrant was employed in all accurate surveys, although Römer had previously shown the superiority of the reflecting circle with three verniers. Both instruments, however, as well as all reflecting instruments, can only measure the angular distance between two objects; that is, an angle, in whatever plane, which happens to include them and the eye; from which angle the horizontal one has to be found by calculation. The first example of a survey conducted with an entire circle is said to be that of Zealand, by Bugge, in 1762-8. Borda afterwards invented the *repeating* circle, for adding mechanically any number of successive measures of the same angle, so that the average of the whole might be more accurate than any single observation could be. This still leaves the reduction of the angular distance to a horizontal and

a vertical angle to be made by computation. This has continued the chief instrument in French surveys; but Englishmen have a tendency to place more confidence in mechanism, and to substitute it, wherever possible, for computation, although this necessarily involves both more expense and more causes of error. The theodolite makes this reduction *mechanically,* which of course renders the observer dependent on two or three more instrumental *adjustments* than those required by reflecting instruments; and also on a *firm fixture* to the earth, while those, however delicate, can be held in the hand, the measure becoming, by Hadley's admirable contrivance, independent of any motion in the quadrant itself. Ramsden completed his great theodolite in 1787, the circle of which is 3 feet in diameter. This was used for a triangulation to connect the observatories of Greenwich and Paris. The principal triangles of the English, Irish, and Indian surveys have been observed with this instrument, or with instruments exactly similar.

The theodolite, as at present constructed, consists chiefly of a pair of parallel plates, with adjusting screws, fitting on a tripod, (similar in construction to the supports to the Y and other levels [see LEVELLING]); a horizontal limb for measuring horizontal angles, and a vertical limb for measuring vertical angles.

The two parallel plates, L and V, Fig. 2156, are circular, and fit accurately one on the other. The lower plate has a projecting chamfered edge graduated to half degrees: the upper or *vernier* plate has portions of its edge chamfered off, so as to form with the chamfered edge of the lower plate continuous portions of the same conical surface. The chamfered part of the upper plate is graduated so as to form the verniers by which the limb is subdivided into single minutes. A 5-inch theodolite, such as that represented in Fig. 2156,[1] has two such verniers, 180° apart. Larger ones have 3 at distances of 120°, by which, in their average reading, the error of centering is entirely counteracted. The lower plate of the horizontal limb is attached to a conical axis, which passes through the upper parallel plates, and terminates in a ball fitting in a socket on the lower plate. The axis is hollowed for the reception of a similar conical axis ground accurately to fit it, so that the axes of the two cones may exactly coincide, the perfection of the instrument for horizontal measurement depending greatly on the axes of the two cones being identical. The upper or vernier plate is attached to the internal axes, so that while the whole limb can be moved through any desired horizontal angle, the upper plate only can also be moved through any desired angle, when the lower plate is fixed by the clamping screw C, which tightens the collar D. T is a slow motion screw, which moves the whole limb through a small space, for the purpose of adjusting it more perfectly after the collar D has been tightened by the clamping screw C. *c* is a clamping screw for fixing the vernier plate to the lower plate, and *t* is a tangent screw for imparting a slow motion to the vernier plate upon the lower plate when so clamped. There are two spirit levels B B on the horizontal limb, at right angles to each other, and a compass G in the centre between the supports F F of the vertical limb. The vertical limb N N is divided on one side at every 30 minutes each way from 0° to 90°, and subdivided by the vernier attached to the compass-box to single minutes. On the other side is marked the number of links which are to be deducted from each chain, for various angles of inclination, so as to reduce those distances which are measured along ground which rises and falls at such angles to corresponding horizontal distances. The axis A of the vertical limb must rest upon its supports F F, in a position truly parallel to the horizontal limb, and the plane of the limb N N should be truly perpendicular to its axis. The vertical limb N N carries a bar with two Y's, which support the telescope, and below the telescope is a spirit-level S S, attached to it at one end by a joint, and at the other by a capstan-headed screw. The axis A can be fixed by a clamping-screw C, and the vertical limb can be then moved through a small space by the slow motion screw *i*.

Previous to taking an observation, the telescope must be adjusted for parallax and for collimation; the horizontal limb must be adjusted to set the levels

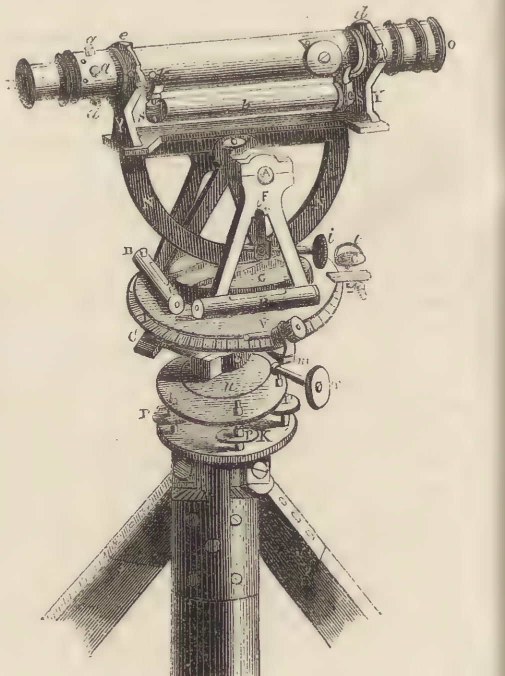


Fig. 2156. 5-INCH THEODOLITE.

to indicate the verticality of the azimuthal axis; and the vertical limb must be adjusted to set the level beneath the telescope to indicate the horizontality of

(1) Our figure represents the theodolite as improved by Mr. Castle, and engraved in his "Treatise on Land Surveying and Levelling," 2d ed. 1845. In our description we have chiefly followed Mr. Heather's excellent little "Treatise on Mathematical Instruments," published in Weale's Rudimentary Series. There is a masterly article on the "Theodolite" in the *Penny Cyclopædia.*

the line of collimation. The adjustments for parallax and collimation are the same as those noticed under LEVELLING for the Y level. The adjustment of the horizontal limb is made by first setting the instrument as accurately as possible by eye, by moving the legs of the stand until the bubbles in B B are nearly central, and the plummet which is suspended from a hook under the body of the instrument hangs freely above the centre of the station. One leg should be moved, and each leg is capable of a double motion. The collar D is then tightened by the clamping screw C; the vernier plate is unclamped, and turned round until the telescope is over two of the parallel plate-screws. The bubble *b* of the level S S is to be brought beneath the telescope to the centre of its run, by turning the tangent screw *i*. The vernier plate is turned half round, and the telescope again brought over the same pair of parallel plate-screws; if the bubble of the centre be not in the centre of its run, it must be brought back to the centre, half way by turning the parallel plate screws over which it is placed, and half way by turning the tangent screw *i*. The operation is to be repeated until the bubble remains truly in the centre of its run in both positions of the telescope, and the vernier plate being turned round until the telescope is over the other pair of parallel plate screws, the bubble is to be again brought to the centre of its run by turning these screws. The bubble will now retain its position while the vernier plate is turned completely round, showing that the interior azimuthal axis about which it turns is truly vertical. The bubbles of the levels B B being brought to the centre of their tubes will therefore be adjusted to show the verticality of the internal azimuthal axis. The vernier-plate having been clamped, the collar D is to be loosened by turning back the screw C, and the whole instrument moved slowly round upon the external azimuthal axis; and if the bubble of S S beneath the telescope maintain its position during a whole revolution, the external azimuthal axis is truly parallel with the internal, and both are vertical at the same time; but if the bubble does not maintain its position, it shows that the two parts of the axis have not been accurately ground, and that the instrument is imperfect.

In adjusting the vertical limb the bubble of the level S S being in the centre of its run, the telescope (with the level attached and already adjusted parallel to its line of collimation) is to be reversed, end for end, in the Y's, and if the bubble do not remain in the same position, correction for 1-half the error is to be made by the capstan-headed screw at one end, and for the other half by the vertical tangent screw *i*. The operation is to be repeated until a satisfactory result is attained. On turning the telescope a little to the right and to the left, if the bubble do not remain in the centre of its run, the level S S must be adjusted laterally by means of the screw at the other end. This will probably disturb the first adjustment, and the whole must then be carefully repeated. By means of the small screw which fastens the vernier of the vertical limb to the vernier-plate over the compass box, the zero of this vernier may be set to the zero of the limb, and the vertical limb will be in perfect adjustment. In large theodolites a second telescope is placed beneath the horizontal limb, for the purpose of detecting any accidental derangement of the instrument during an observation, by noting whether it is directed to the same point of a distant object at the end of an observation as it was at the beginning. The vertical limb also, in the larger theodolites, admits of an adjustment to make it move accurately in a vertical plane when the horizontal limb has been set in perfect adjustment. And also in small theodolites, when the vertical limb is permanently fixed to the horizontal, Mr. Heather remarks, that an instrument which will not bear the following test should be returned to the maker for better adjustment. The azimuthal axis having been set truly vertical, direct the telescope to some well-defined angle of a building, and making the intersection of the wires exactly coincide with this angle near the ground, elevate the telescope by giving motion to the vertical limb, and if the adjustment be perfect, the intersection of the cross-wires will move accurately along the angle of the building, continuing in coincidence with it. A plumb line suspended from the cornice would however be more trustworthy than the verticality of the angle itself.

In an extensive survey the principal points should be determined by a system of triangles proceeding from an accurately measured base of considerable length. The angles of these triangles should be observed with a large and perfect theodolite, the corrections for the curvature of the earth, refraction, &c. being applied. The boundaries of the space to be surveyed being accurately determined, and a series of stations laid down throughout, the spaces included between these stations may be subdivided into spaces of 3 or 4 miles, the boundaries of which may be surveyed by a *traverse*, i. e. with a chain and a portable theodolite, and the details of the country within these spaces may be sketched by means of the prismatic compass. See SURVEYING.

THERMOMETER. Having, in the article HEAT, stated at some length the laws which regulate the action of instruments constructed for the measurement of temperature, and having also, under STEAM and STEAM-ENGINE, given a further exposition of those most important laws, our attention will be chiefly confined, in the present article, to a description of the modes of preparing thermometrical instruments, the methods of using them, and the reliance which is to be placed upon their indications.

Thermometrical instruments may be divided into three classes:—1st. Those which are intended merely to compare the temperatures of bodies, and to which the term *thermometer* is usually restricted. 2dly. Those which are intended to compare the quantities of sensible heat evolved by different actions or contained by different bodies: such instruments have been usually called *calorimeters*. 3dly. Those which are intended to compare the effects of different radiations or heating rays. As their indications depend on the *difference*

of temperature between their different parts, they have been named *differential* thermometers.

The first thermometer was constructed about the beginning of the 17th century. It consisted of a tube

Fig. 2157.

t, Fig. 2157, open at one end, and a glass bulb B at the other: the air in the bulb being first expanded by heat, the open end of the tube was inserted into the coloured liquid in the cup *c*. As the bulb became cool, the enclosed air contracted, and a portion of the liquid ascended the tube, by atmospheric pressure on the surface of the liquid in the cup, until the liquid in the tube equalled the bulk of air expelled by the heat. Any process tending to heat the bulb above the temperature of the surrounding air would cause the enclosed air to expand; thereby depressing the liquid in the tube; but if the temperature of the bulb were lowered beyond that of the surrounding air, the enclosed air would contract, and more liquid be forced into the tube. If a scale of equal parts were applied to the tube, a rough idea would thus be afforded of the differences in temperature of bodies affecting the bulb. Instruments of this kind are called *air-thermometers;* and formerly *weather glasses,* since they served to indicate cold and warm weather.

This instrument was improved by Boyle, who exchanged the cup *c* for a bottle, Fig. 2158, into the neck of which a tube was cemented, so as to confine a portion of air in the bottle instead of in the bulb, which was dispensed with, the tube being open at both ends. The bottle could thus be dipped into liquids, and their relative temperatures compared; but

Fig. 2158.

the open tube, and the evaporation or contamination of the liquor contained in it, were objections which prevented this form, and other attempts at improvement, from having any value in scientific observations.

The Florentine Academicians saw the necessity of removing the registering fluid from the pressure of the air, and also of obtaining a scale with *fixed points,* such as should be applicable to all thermometers. Their instrument depended on the expansion of spirits of wine instead of air, and the mode of construction was as follows:—A tube, with a bulb at one end and open at the other, was heated, and when a portion of the air was expelled, the open end was plunged into spirits of wine, which, as the bulb cooled, ascended into the stem: the bulb was then held downwards over a flame, so as to boil the spirits and expel the remaining portion of air. While the vapour was issuing from the end of the tube the flame of a blowpipe was applied to it, thus melting the glass and sealing it hermetically. The application of a scale was less happy than the structure of the instrument. The points selected for the graduation were, 1st, the cold of ice and snow for the lower limit, and, 2dly, the greatest summer-heat of Florence for the upper limit. As these points are variable, they were of no value for the purpose intended.

On the introduction of this thermometer into England, the first improvement of Boyle was to substitute *coloured* spirit for colourless. He proposed to fix one point of the scale by observing the height of the liquid in the stem when the bulb was placed in thawing oil of aniseed; a temperature which he preferred to that of melting ice, because it could be procured at any time of the year; for this oil melts or freezes at about 50°, and is therefore in this country seen about as often in the solid state as in the liquid. Hooke is thought to have suggested the temperature of freezing water as one of the fixed points; Halley proposed the boiling point of spirits as another. The differences of opinion respecting the standard minimum of temperature arose from the supposition that the freezing point of water was higher in one country than in another.

As spirit boils at a comparatively low temperature, the tubes filled with it were liable to burst on being exposed to temperatures beyond their boiling points. Newton proposed to remedy this defect by using oil instead of spirit; but this was found to be very sluggish in its motions within the tube, to adhere to it strongly, and to vary in fluidity at different temperatures.

The present mode of rendering thermometers comparable with each other is commonly ascribed to Newton, who was the first to take advantage of the fact, that whenever a thermometer is placed in *melting* snow or ice, the liquid always stands at the same point of the tube, and that the boiling point of water is almost equally constant in all ordinary states of the weather. Now, if we divide the space between these two points into any arbitrary number of degrees, and continue degrees of the same magnitude both upwards and downwards, all thermometers thus made will indicate the same degree when exposed to the same temperature. Before this capital invention of Newton, the instrument could scarcely be said to be more than a toy; but it now became almost an artificial organ of sense; the observations made with it being comparable, however widely they might be separated by time or place.

Another decided improvement was the adoption of *mercury* enclosed in a bulb and tube purged of air. Halley conceived the idea of employing mercury; but he rejected it on account of the small amount of its expansibility, which he estimated at $\frac{1}{74}$ from freezing to boiling water; but it has since been found to be $\frac{1}{55.5}$; that is, $55\frac{1}{2}$ measures at 32°, expand into $56\frac{1}{2}$ measures by being heated to 212°. Römer is said to have first adopted this important improvement and also to have constructed Fahrenheit's scale. Fahrenheit was an instrument maker, a native of Dantzic, residing at Amsterdam: his thermometers were known over Europe early in the eighteenth century.

The advantages attending the use of mercury as the thermometric fluid are—1. It enlarges in bulk more equably for equal increments of heat than most other

liquids. 2. From its great density it is more easily freed from air than either alcohol or oil; a quality of much importance in the construction of these instruments. 3. It has a very convenient range; for while oil becomes viscid and very tenacious at low temperatures, and water[1] and alcohol boil before they attain a high temperature, mercury will retain its liquidity unimpaired for a range of more than 700°. 4. It accommodates itself more speedily to the temperature of surrounding bodies than many other liquids. It was stated under HEAT, that a less quantity of heat is required to raise a given quantity of mercury to a certain temperature, than is necessary to raise an equal quantity of water to the same temperature; and this is in effect the same as saying that mercury becomes heated and cooled more speedily than water. This property is due to the metallic nature of mercury; metals are the best conductors of heat, and a fluid metal would conduct heat from one particle to another more rapidly than water or any other liquid.

As liquids do not follow the same law of expansion, that is, do not equally increase their expansibility with increase of temperature, it follows that two thermometers made with different liquids, although both be graduated in the manner above described so as to coincide in their indications of two fixed points, would nevertheless not coincide exactly when the temperature was at any other point. Thus, as mercury is more equable in its rate of expansion than any other liquid, a thermometer of any other liquid, although made to coincide with the mercurial one at the boiling and freezing points of water, would yet give a rather lower estimate of all temperatures between these two points, and a rather higher estimate of all temperatures above boiling and below freezing. Now in the comparison of scientific results at different times and in different places, it is evidently necessary to adopt some standard of universal reference; and in the case of the thermometer pure mercury is the standard. The methods of obtaining it pure are given under MERCURY.

The glass capillary tubes which are prepared for the construction of thermometers should be precisely equal in diameter throughout, if we would have them measure equal increments of bulk. But in fact the tubes as obtained from the glass-houses are generally frusta of very elongated hollow cones, which by extension become more or less perfectly cylindrical. We may see how this happens by drawing out a thread of sealing-wax, which will always be larger at the ends than towards the middle. If one part of the bore be larger than another, a division at that part in a scale of equal parts would belong to a greater change in the volume of the mercury than a division at the other part, where the diameter is less. In order to determine the value of one of these tubes a drop of mercury may be drawn into it so as not to occupy a space in the bore of more than $\frac{1}{4}$ inch. The mercury is to be gradually moved through the tube from one end to the other, and kept stationary at different parts by holding the tube horizontally: the space which it occupies in the tube at different places is to be carefully measured; if this be the same at every part, the bore is evidently uniform throughout; but if the mercury occupy a less extent at one part than at another, the bore must vary in diameter, and hence cannot afford accurate results when used as a thermometer tube. The application of this test will enable the careful maker to select such tubes or portions of tubes as most nearly approach to perfect accuracy of bore. Thermometer tubes are sometimes made with an elliptical bore, to allow a small column of mercury to be more visible when expanded at right angles to the line of vision.

When the tube is selected a bulb is blown upon it at one extremity by softening the end in the flame of a table blow-pipe, and tying the other end to a bottle of India-rubber containing dry air: on compressing the bottle the air will expand the softened glass into a bulb. Air from the mouth would be injurious in this operation on account of the moisture which would be introduced into the tube. The size of the bulb must depend on the purposes to which the thermometer is to be applied; but, of course, the larger the bulb, in proportion to the stem, the more sensitive will the thermometer be to changes of temperature, for the greater will be the rise or fall produced by a change of bulk bearing any given ratio to the whole bulk of the liquid. But although there is no limit to the size or length allowable in a thermometer used only for indicating atmospheric temperature, it is otherwise with an instrument intended for discovering the temperatures of small bodies, for unless its bulb be much smaller than the bodies to which it is applied, it will sensibly alter their temperature, and not acquire the exact temperature which they had maintained in its absence.

As the pressure of the air acts more equally upon a spherical than on a cylindrical or pyriform body, the spherical is preferred; but when the bulb is very large in proportion to the stem, one of the two latter is adopted. With bulbs of large size containing mercury, a slight pressure of the fingers, apart from their natural heat, causes the mercury to ascend in the stem: and with such bulbs the varying pressure of the atmosphere has an influence on the capacity of the bulb. It may seem strange that the atmospheric pressure should have more effect in compressing the bulb than the weight of the mercury in distending it; but such is always the case in thermometers of ordinary length.

The bulb is filled with mercury much in the same way as the first thermometer, Fig. 2157, was filled with liquid, viz. by applying heat to the bulb so as to rarefy the air, and in allowing it to cool with the open end under mercury, a portion thereof will enter the stem and bulb. The tube should be placed in a nearly horizontal position, with its open end below the surface of the mercury. Heat is again applied to the bulb, and the mercury in it is boiled: the vapour of mercury expels the remaining air, and when the

(1) Water is also inapplicable as a thermometric fluid from the unparalleled singularities of its changes of bulk at low temperatures. See HEAT.

flame is withdrawn the vapour will gradually be condensed into the liquid form, and the tube and bulb will be entirely filled with mercury forced up into them by atmospheric pressure. Another plan for completing the filling of the bulb and tube is to roll a slip of clean writing-paper round the open end of the stem, and tie it firmly, so that it may form a cylindrical cup capable of holding as much mercury as the bulb. A drop of mercury is placed in the paper cup, but it descends no further on account of the capillary bore of the tube, which will not allow the mercury to enter by its own unassisted weight. On applying a flame to the bulb the vapour of mercury soon rushes up into the paper vessel through the upper mass of mercury, and on removing the flame the vapour of mercury left in the bulb and stem suddenly returns to the liquid form, leaving a vacuum which is filled by the mercury in the paper cylinder descending into the tube, its weight being assisted by that of the air above it. The value of this plan is, that moisture and air are completely expelled from the bulb and tube.

Another plan is to blow two bulbs on the tube instead of one, as shown in Fig. 2159, one near the extremity, and the other near the other end. The

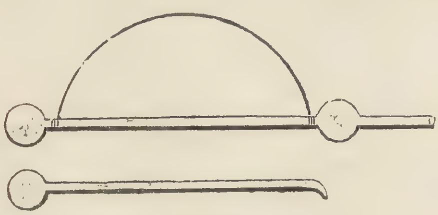


Fig. 2159.

latter bulb is heated so as to expel a portion of the air, and the open end just beyond it is immersed in pure mercury. As the glass cools, a portion of the metal is pressed up into that bulb. The tube is then held with the bulb at the other end downwards, and this latter bulb is heated, the air rarefied, and partly expelled through the mercury, a portion of which is afterwards pressed down into the lower bulb, when it has cooled. In this way the bulb at the end of the tube is entirely filled, and a portion of the mercury is left in the other bulb. The tube is now held by a piece of iron wire over a charcoal fire, and heated so as to vaporize part of the mercury, by which means air and moisture are expelled: the open end is then closed with wax, and the tube removed from the fire: on inclining it, a portion of the mercury falls into the stem from the upper bulb, and it is made to settle at the desired height. If too much, or not enough, mercury be in the lower bulb and stem, portions of it can be transferred to or from the other bulb by inclining the stem to one side or the other. The adjustment being made, the flame of a blow-pipe is applied a little below the upper bulb, and the tube is permanently closed and detached from the upper bulb, as shown in the figure. By the other methods of filling, the tube is finally closed by first gently heating the mercury in the bulb until it rises to the point at which the sealing is to be made. The excess of mercury which filled the tube, when cold, is thus expelled, and the bulb and tube still left full of mercury at the increased temperature. The tube is softened by the flame of a blow-pipe, the heat from the bulb being removed, and the stem is thus hermetically sealed by the fusion of the glass at the end.

As the indications of the thermometer depend on the rise and fall of the mercury in the tube, the bulb and a portion only of the stem must remain filled after the sealing and cooling of the tube, so that in any depression of the mercury by cold there shall still be a portion of the mercury in the stem to indicate its amount, and that, in expanding by heat, the tube should be sufficiently long to allow the utmost range to the metal, while no other fluid should be above it to counteract its ascensive force. A good test of the absence of air and moisture, as well as of the purity of the metal, is to invert the tube, when, unless the bore be very small, the mercury should fall easily to the sealed end, so as to occupy the whole of the bore.

Supposing a number of tubes to have been filled, a graduated scale is attached to each by first finding a fixed point for each tube, if of moderate range, and two fixed points if the range be above the boiling point of water. If the tubes be placed in a vessel containing melting snow or ice, the mercury will sink in each stem down to a certain point, at which it will remain stationary during the whole of the liquefaction. [See HEAT.] The height of the mercury may not correspond in any two stems, but each stem will have its own fixed point peculiar to itself; the amount of depression of the mercury depending, 1st, on the temperature of melting ice or snow, which is constant; 2d, on the size of the bulb compared with the stem, which may be variable in each case; 3d, on the quantity of mercury enclosed in the bulb and stem, which may also be variable. A scratch is made with a file on the outside of the tube, exactly opposite the point at which the column of mercury terminates. This is called the *freezing point*, or temperature of melting ice, and is the same in every part of the world, at every season of the year, and is not influenced by the temperature of the apartment in which the graduation is conducted.

The determination of the boiling point is more difficult, because it is subject to variation with the variations in atmospheric pressure. [See EBULLITION.] But supposing the barometer to mark 30 inches, or mean pressure, the boiling point of pure water would be constantly 212°. But whatever the pressure, if a number of thermometer tubes be suspended in a vessel of water which is being heated, the mercury in each tube will gradually rise in proportion as the temperature of the water rises: but the moment it begins to boil, the mercury will cease to rise: it will remain stationary until the whole of the water has evaporated. A mark made opposite the end of the mercury in the tube will thus give the water boiling point of the thermometer in each case. This may also stand at different heights in different tubes, for similar reasons to those given in the case of the freezing point.

A Committee appointed by the Royal Society about the middle of the last century, to inquire into the principles which regulate the construction of the thermometer, recommended that the boiling point be fixed when the barometer stands at 29·80 inches; that the bulb be not immersed in the water, because they found that according to the depth of the immersion the mercury rose in the tube, the steam in fact being in such case under a slight increase of pressure. They recommend as a boiler a vessel of tinned iron, with an easily fitting cover rendered steam-tight by a ring of woollen cloth; the cover to have 2 apertures, one to act as a chimney with an area of not less than half a square inch, and about 3 inches high, to convey away the steam from the boiling water, and the other hole for a cork through which the thermometer-stem is to pass in such a manner that the bulb shall not touch the surface of the water, but be surrounded with steam: no more of the stem is to be exposed above the cork than is necessary to show the height of the mercury when the water is boiling briskly. When matters are thus adjusted, a thin plate of metal is to be placed over the chimney to prevent the escape of the steam; heat is applied to the bottom of the boiler, and when the mercury has risen to the temperature of the steam it is to be allowed to remain at rest for a few minutes, and then its height is to be accurately marked with a file.

When the barometer does not stand at 29·80 in., the boiling point may still be adjusted to that pressure by means of a table of corrections of which the following is a portion:—

Thermometer immersed In Steam. Height of Barometer.	In Water. Height of Barometer.	Correction in 1,000th of the interval between freezing and boiling points.	
	30·60	10	
	·50	9	
30·71	·41	8	
·50	·29	7	
·48	·18	6	
·37	·07	5	Lower.
·25	·95	4	
·14	·84	3	
·03	·73	2	
29·91	·61	1	
·80	·50	0	
29·69	29·39	1	
·58	·28	2	
·47	·17	3	
·36	·06	4	
·25	28·95	5	
·14	·84	6	Higher.
·03	·73	7	
28·92	·62	8	
·81	·51	9	
·70		10	

It has been observed that mercurial thermometers slowly change their fixed points, in consequence, it is supposed, of a diminished capacity of the bulb, due to the atmospheric pressure constantly exerted on its exterior and not counterbalanced by an equal pressure from within. Professor Daniell examined two thermometers constructed with much care by the Hon. Henry Cavendish. "The mercury in the balls of both flows freely into the tubes when reversed; and when suffered to fall sharply, strikes the end with a metallic sound. The same *click* may be heard in the bulbs when it is permitted to fall back, and the cavity closes without the slightest speck. They are mounted upon common deal sticks, and the graduation, which is only continued for a few degrees above the freezing point, is engraved upon a small slip of brass. The degrees are very large, and they are distinctly divided into tenths. Each degree of No. 1 occupies a space of ·208 inch, and of No. 2, ·130 inch. The scratch upon the glass for the freezing point is very visible in both. It is difficult to say for what purpose they were originally made, but evidently for some experiments upon the freezing point of water; and if they had been expressly constructed to verify the present point, they could not have been better contrived for the purpose. The bulbs of both were plunged into pounded ice, in which they were left for half an hour, and the height of the mercury was carefully taken by two observers with the aid of magnifying glasses. The result of the examination was that in No. 1 the freezing point upon the scale was 0·4° too low, and in No. 2, 0·35°. There can be little doubt, I think, that the right cause of the phenomenon has been assigned, viz. the change of form and capacity which the glass undergoes from the pressure of the atmosphere upon the vacuum of the tube." [1]

The principal amount of contraction of mercurial thermometers takes place soon after the tube is sealed: and hence it has been recommended to allow 10 or 12 months to elapse between the sealing and the graduation of a thermometer.

The freezing and boiling points having been fixed, the interval between the two includes that portion of the tube which corresponds to the expansion of the mercury between these two temperatures; and since this expansion is constant, it follows that the proportion which the capacity of the tube between these two points bears to the volume of mercury included in the instrument at the temperature of melting ice must be constant also. The capacity, therefore, of the tube between the above points will be proportional to the capacities of the bulb and stem below the freezing point. This is a consequence of the uniform expansion of mercury when subjected to the same limits of temperature. Now between the boiling and freezing points of water the expansion of mercury amounts to $\frac{1}{55\cdot5}$th part of the volume which it occupies at the temperature of melting ice; therefore the capacity of the tube between the two fixed points must always be equal to $\frac{1}{55\cdot5}$th part of the capacity of the bulb together with that portion of the stem below the freezing point. The varying lengths, therefore, of the intervals between the two fixed points in different thermometers will be found to arise from the different proportions which the capacity of the bulb bears to the bore of the stem. Hence a plan is sometimes adopted in warm climates where ice and snow are unknown, of graduating the thermometer

(1) "Elements of Meteorology," vol. ii. 1845. It should also be stated that Bellani attributed the cause of this remarkable phenomenon to molecular action, meaning thereby that a considerable time elapses before the particles of glass assume their final positions after the bulb is blown.

by means of the boiling point alone. For this purpose the stem is graduated by means of a drop of mercury of known weight, which is moved about in various parts of the tube; a bulb is then blown upon one end of the stem, and mercury is introduced in the usual manner, the quantity of which is accurately weighed; and since the space between 32° and 212° corresponds to an expansion of mercury equal to $\frac{1}{55\cdot5}$th, the number of graduated spaces between the boiling and the freezing points may be computed. Thus, suppose the weight of the included mercury to be 333 grains: then $\frac{1}{55\cdot5}$th of that quantity, or 6 grains, corresponds to 180° of Fahrenheit's scale. If the initial measuring column were 0·6 of a grain, then 10 of those spaces would comprehend the range between freezing and boiling water. Hence if the boiling point is known, the freezing point can be set off; each space being successively occupied by the drop of mercury into 18 equal parts or degrees.

Fig. 2160.

The Florentine Academicians directed that the principal divisions of the tube should be marked "by a little button of white enamel; and these may be further subdivided by the eye, and the intermediate degrees marked by buttons of glass, or of black enamel." The Florentine thermometer is represented in Fig. 2160. It is still the custom, in chemical thermometers, for example, which have to be plunged into corrosive liquids, to mark the graduations on the stem itself; or the lower part of the separate scale is made to fold up on a hinge, so that the bulb and a small portion of the stem may be immersed in liquids without injury to the scale.

But the usual method is, when the tube has the two fixed points marked upon it, to attach it firmly to a frame of hard dry wood, such as boxwood, as in Fig. 2161, or of metal, ivory or glass. Opposite to the freezing and boiling points a line is engraved, and the space between the two is divided into 180 equal parts or *degrees;* the space between any two degrees depending on the space between the boiling and freezing points. These degrees are continued above and below the two fixed points, the numeration commencing 32° below the freezing point and reckoning upwards; so that the boiling point is 212°.[1] This is Fahrenheit's scale. By immersing the bulb in a mixture of salt and snow, he caused the mercury to sink to a point which he erroneously supposed to indicate the greatest amount of cold that could be produced, and from such point he commenced his scale, calling it zero or 0°; between this temperature and that of melting ice he marked 32°, and by continuing to divide his scale equally he arrived at the 212th degree, or the boiling point of water. But when temperatures were discovered below zero, and it was necessary to continue the scale downwards, the negative sign — was prefixed to each degree, thus involving the absurdity of negative signs for positive quantities; for a temperature below zero is as much a positive quantity as a temperature above that point. The number of degrees above zero has for a prefix the positive sign +. Thus —10° signifies 10° below zero, and + 10° implies 10° above zero.

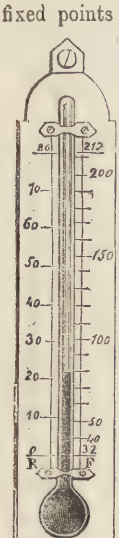


Fig. 2161.

Fahrenheit's scale is not used in France. Previous to the Revolution, Réaumur's scale was adopted. Réaumur used spirits of wine in his thermometer; but De Luc substituted mercury. The fixed points on this scale were the same as on Fahrenheit's; but the numeration commenced from the freezing point, which was zero. The interval between the two fixed points was divided into 80 equal parts, so that the boiling point was 80°, and a degree on this scale was longer than one on Fahrenheit's in the proportion of $2\frac{1}{4}$ to 1. To convert a temperature on Réaumur's scale into a corresponding one on Fahrenheit's it is necessary to multiply Réaumur's degrees by $2\frac{1}{4}$, and to add to the product 32° to allow for the distance of the points at which the scale commences. For example:—

Réaumur. Fahrenheit.

$$16^\circ \times 9 = 144 \div 4 = 36^\circ + 32^\circ = 68^\circ$$
$$80^\circ \times 9 = 720 \div 4 = 180^\circ + 32^\circ = 212^\circ$$

To reduce a degree of Fahrenheit's to one of Réaumur, 32° must be subtracted, and the remainder diminished in the proportion of $2\frac{1}{4}$ to 1. For example:—

Fahrenheit. Réaumur.

$$68^\circ - 32^\circ = 36 \times 4 = 144 \div 9 = 16^\circ$$
$$212^\circ - 32^\circ = 180 \times 4 = 720 \div 9 = 80^\circ$$

In 1742, the Swedish astronomer Celsius contrived a thermometer, the scale of which also commenced at the freezing point of water, and the interval between that and the boiling point was divided into 100°. This thermometer was adopted by the French during the Revolution, under the name of *Thermomètre Centigrade*, because it harmonized with their decimal system of weights and measures. Every one of its degrees is equal to $1\frac{4}{5}$ths of a degree of Fahrenheit; for 100° of the former are equal to 180° of the latter. To convert a temperature in Centigrade to the corre-

(1) Messrs. Mackenzie & Blair, of Glasgow, have patented a thermometer-scale printed on vulcanized india-rubber, in order "that such scale surfaces may be elongated or allowed to contract at pleasure, to assist in their adjustment to varying lengths comprehended between any two fixed points. The lines of graduation with their corresponding references are set up in type, and impressions are then taken from this form upon the elastic sheets, either when the latter are slightly elongated, or in their natural condition of tension." The freezing and boiling points having been marked on the tube, "the elastic scale may be stretched to bring the freezing and boiling graduations thereon to correspond exactly with the tube marks; and if the elastic material is of uniform width, thickness, and elasticity, all the intermediate graduations will be found to agree with their corresponding lines of mercurial traverse in the tube. Vulcanised caoutchouc is not materially affected by thermal or atmospheric changes, and when soiled it may be washed." The references being printed on the elastic scales, a much larger number can be inserted in small type than when they are engraved by hand.

sponding temperature on Fahrenheit, the number of degrees must be increased in the proportion of 100 to 180, (which is the same as 5 : 9,) and 32° added to the result. To reduce a degree of Fahrenheit to one of Centigrade, 32° must be subtracted, and the remainder diminished in the proportion of 9 to 5. For example:—

$$\overset{\text{Fahr.}}{212°} - 32 = 180 \times 5 = 900 \div 9 = \overset{\text{Cent.}}{100°}$$

$$\overset{\text{Cent.}}{100} \times 9 = 900 \div 5 = 180 + 32 = \overset{\text{Fahr.}}{212°}$$

In Delisle's scale, used in Russia, the boiling point is 0° and the freezing 150°. Other scales have been proposed, but do not require notice here.

When a thermometer is exposed to heat, not only does the mercury expand, but also the bulb and stem which contain it. By a fortunate coincidence, however, the expansion of the glass is in proportion to that of the mercury; and therefore the change of volume in the mercury bears a constant proportion to the change of capacity in the glass. Hence the variation in the height of the column of mercury must bear the same proportion to the variations which it would experience if the glass were not subject to expansion or contraction. If the mercury and the glass expanded equally with equal changes of temperature, the column of mercury would not appear to rise or fall, but would always be stationary. But as the change of bulk in the glass bears a very small though constant proportion to the change in bulk of the mercury, the expansion of the former does not afford space for the increased volume of the latter, and the mercury therefore is forced up the tube; or *vice versâ*. Hence the variation of the column of mercury arises from the difference of expansion between the mercury and the glass, and this difference, from the freezing up to the boiling point, amounts to $\frac{1}{55.5}$th of the volume of mercury at 32°. Different kinds of glass expand in different proportions; but all expand proportionally to each other and to mercury; and as during the graduation of the thermometer, at the freezing and boiling points, the glass is affected in a manner which is not subject to change in the subsequent practical application of the instrument, it follows that the indications of the columns of mercury may be regarded without reference to the change of bulk of the glass in which the mercury is contained.

It has been stated that the expansion of mercury between 32° and 212° is nearly equal for equal increments of temperature. Above this, the increasing rate of the expansion of mercury becomes sensible, by exposing a mercurial and an air thermometer (the expansion of air being apparently perfectly equable) to the same temperature; taking care to correct the instruments for the expansion of glass. The following table gives the points on the two scales resulting from the same temperatures:—

Air Thermometer.	Mercurial Thermometer	Difference.
212°	212°	0°
299·66	302	2·33
386·69	392	5·31
473·09	482	8·91
558·86	572	13·14
662	680	18·00

Thus it appears that the boiling point of mercury, as measured by its own expansion, is 680°; but by the expansion of air 662°. If a common thermometer be plunged into boiling mercury, it stands at 660°: so that the expansion of the glass is equal to 20°, and almost exactly counteracts the increase of the rate of expansion of the mercury. Hence an accurately graduated mercurial glass thermometer becomes, by this fortunate coincidence, an accurate measurer of the increase of temperature as high as the boiling point of mercury, or about 660° or 662°.

For measuring temperatures below the freezing point of mercury, a spirit thermometer is used, alcohol not congealing by any reduction of temperature hitherto observed. [See ALCOHOL.] The expansion of this liquid, when uniform, may evidently be made to correspond with the degrees on the mercurial thermometer. For low temperatures its indications are to be relied on; but as it approaches its boiling point, or 176°, its rate of expansion is not uniform; indeed, it cannot be safely trusted above 100° Fahr.

For estimating temperatures above the boiling point of mercury, an air thermometer is sometimes used. Dry air, when confined in such a manner as always to preserve the same expansive force, increases in volume $\frac{3}{8}$ths for every 180°, and since its progressive rate of expansion is sensibly uniform for equal increments of heat, an instrument has been constructed in the following manner:—A bulb, or cylinder, with a tube of platinum, is formed similar in shape to that of the common thermometer; and connected with the extremity of the stem or tube, at right angles, is a glass tube of uniform bore, filled with mercury and terminating below in a recurved bulb. The glass tube is graduated into a series of spaces, each equivalent to $\frac{3}{8}$ths of the total volume of the platinum bulb or cylinder with $\frac{3}{4}$ths of its stem. The other fourth is supposed to be hardly influenced by the source of heat. The platinum bulb or cylinder, and $\frac{2}{3}$ds of its stem, are to be plunged into a furnace, and the depression of the mercury by the heated and expanded air within the instrument (pressing on it more powerfully than the external air) will indicate the degree of temperature.

High temperatures were formerly expressed by the degrees of *Wedgwood's Pyrometer*, an instrument constructed on a fallacious principle, and therefore fallen into disuse among accurate observers. But as it is still sometimes referred to by persons who write on science without ever having gone through any experimental training, it may be desirable to state wherein the error of this instrument consists. When clay is exposed to a high temperature it undergoes a permanent diminution both of bulk and weight in consequence of the expulsion of water from its pores. [See ALUMINA—CLAY.] Wedgwood further supposed that this contraction was always proportional to the highest temperature to which the clay had been exposed. But this is now known to be an error, since the exposure to a lower heat for a longer time will produce as much contraction as the exposure to a more intense heat for a shorter time. The indica-

tions of this instrument therefore are quite useless. They were obtained by exposing small cylinders of very pure clay, about ½ inch in diameter, to the heat intended to be measured, and afterwards when cold measuring their contraction very accurately by observing how much further than before they would slide along a groove left between two perfectly straight brass rulers fixed on a board so as to be rather nearer together at one end than at the other, a scale being marked on one of these rulers.

When the fallacy of this instrument became known, many attempts were made to apply the expansions of other solids, such as metals, to the measurement of high degrees of heat, but without success, the chief difficulty arising from the fact of the expansion being only temporary, and taking place while the metal was in the furnace, and of course beyond the reach of observation. It was necessary therefore to make it register its own expansion by some mark that would remain when it was cold. This was first satisfactorily effected by Professor Daniell in a pyrometer represented in Fig. 2162, consisting of two distinct parts, the *scale*, No. 1, and the *register*, No. 2. The register is a solid bar of blacklead earthenware, D D, No. 2, 8 inches long, $\frac{7}{10}$ths of an inch wide, and of the same thickness. A cavity *o* is drilled down this, $\frac{3}{10}$ths inch in diameter, and 7½ inches deep. At the top of the bar and on the nearer side at *p p*, about $\frac{6}{10}$ths inch in length of its substance is cut away to the depth of half the diameter of the bore. When a bar of any metal 6½ inches long is dropped into this cavity, it rests against the solid end of the bar; and a cylindrical piece of porcelain *q q*, about 1½ inch long, serving for the index, is placed upon the top of it, which index being partly in and partly out of the cavity in the bar, is kept firmly in its place by a band of platinum *r*, which is tightened by a small wedge *s*. It is obvious that when such an arrangement is exposed to a high temperature, the metallic bar in the cavity *o* will force the index *q q* forward to the amount of the excess of its expansion over that of the blacklead; and that when again cooled it will be left at the point of greatest elongation. The contraction which the blacklead clay may suffer from the great heat is not likely to lead to any fallacy; as the greatest expansion of the metal will have been completed at the point of time when its earthenware case may slightly contract, and the index will still mark the point of the furthest extension.

The contrivance by which the expansion of the metal is measured must now be noticed. The amount is in all cases small, but it is rendered more perceptible by the means employed. The application of the scale to the register must be made before the exposure of the latter to the fire, and also after its cooling: and the object sought is to ascertain precisely how much the index *q q* is pushed out by the expansion of the metal when heated. The scale is made of two rules of brass, accurately joined together by a right angle at one of their long edges, and fitting square upon two sides of the blacklead bar, and of about half its length. The greater rule is A A, No. 1, and the smaller, or, as it is called, the *frame a a a'*, fits on the under side of A A, and is adjusted by the screws *b b*. When the scale is thus fitted to the register, the projecting piece of brass *a'* rests upon the

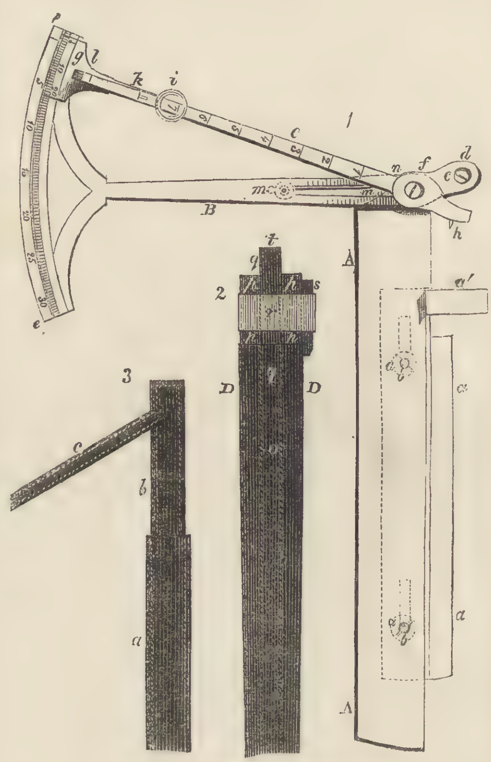


Fig. 2162. DANIELL'S PYROMETER.

ledge under the platinum band *r*; so that in this way the scale is firmly united to the register. At the upper extremity of this frame is fixed an apparatus, which corresponds to a pair of proportional compasses, the whole of which is movable at a screw *c d*, which part projects so as to come exactly over the hole in the register. The connexion of the two arms B C is made by a screw below *f*. The arm B, which is 5½ inches long, carries an arc of a circle *e e* whose radius *f g* is 5 inches; this arc is graduated into degrees and thirds, subdivided by the vernier *g* into minutes, which may be read off by the magnifying glass at *i*, the stem of which lies on the bar C between *k* and *l*, and is so arranged as to bend twice in order that the glass may project horizontally over the vernier. The other end of the lighter arm C terminates in a point *h*, which is ½ inch from *f*, or $\frac{1}{10}$ th of the radius *f e*. At *m* is a steel spring fixed in a cavity cut out of the arm B; it exerts a pressure on a small pin *n* in the arm C, and throws the radius back to the commencement of the arc. In making a measurement this point *h* is fixed into a small hole in the index at *q*. When this is effected, the part *h f* acts as the smaller arm of a lever, and the radius *f g* will point to a degree on the arc *e e* different from that to which it pointed on the previous application of this apparatus

to the bar before it was heated; hence, the arc described by the point h is increased tenfold on the segment at $e\,e$. The small arc is of course due to the index at $q\,q$ having been pushed out when the metal expanded, which arc is thus appreciated by taking its decuple. The chords of these arcs are easily found by computation, and that of the smaller gives the amount of the advance of the index, or of the expansion of the metal. The degrees given on this scale are made to bear relation to those of the mercurial scale; so that as the ratio is marked on the instrument, the degrees of the scale are convertible into those of Fahrenheit.

One advantage of this pyrometer is, that the material whose expansion is to be measured is quite detached during the heating process from the instrument of measurement; so that the scale, vernier, &c. not being exposed to the fire, are not subject to an expansion which would interfere with the correctness of the results.

Professor Daniell in his account of this instrument[1] gives the rule for calculating the linear expansion of the metal bar, by means of the arc described by the smaller divisions of the graduated arm. We must refer to the original memoir for these details; but the following are given as the elongations of a bar of platinum 6½ inches long, and the corresponding changes of temperature indicated by a displacement of the index through various small arcs. The first column shows the arc; the second the linear expansion of the bar of metal; and the third, the temperature:—thus if the radius move 1°, the bar is elongated ·00872 of an inch, and the temperature is 450°.

Arc.			Elongation.		Temperature.
1°	0′	=	·00872 Inch	=	450°
0	30	=	·00436 ,,	=	225
0	20	=	·00290 ,,	=	150
0	15	=	·00218 ,,	=	112
0	10	=	·00145 ,,	=	75
0	5	=	·00072 ,,	=	37
0	2	=	·00029 ,,	=	15
0	1	=	·00014 ,,	=	7·5

Some of the results obtained by Daniell's pyrometer are given in the table which accompanies the article Heat. By an arrangement shown in No. 3, Fig. 2162, bars of metal can be exposed to the vapour of mercury. a is an iron tube, 2 inches in diameter, closed at the bottom; b is a blacklead tube, closed at the top, and fitted to the mouth of a by grinding; c is a smaller blacklead tube, projecting from the side of the latter, and fitted by grinding. This arrangement forms a kind of alembic in which mercury may be boiled, and the expansion of bars of metal taken at that temperature. The results obtained in this way were found to be in very close agreement with those obtained by some of the best French experimentalists.

Several different forms of pyrometers, or thermometers of solid substances have been constructed by Breguet of Paris. One of them depends on a principle that has often been applied in the construction of compensation pendulums, balance wheels, &c., [see Horology,] viz. that if two flat bars or plates of different metals, such as steel and brass, be placed face to face and riveted or otherwise fastened together near their ends, as in Fig. 2163, this compound bar will remain flat only so long as the temperature is unaltered. An exposure to a higher temperature will cause it to warp or bend, in consequence of the more expansible metal, brass, becoming longer than the

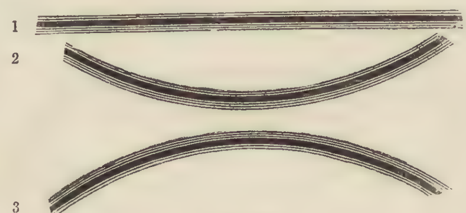


Fig. 2163.

other, and therefore becoming convex, as in No. 3, while a diminution of temperature will produce a curvature the other way, as in No. 2, for the metal which expanded most will also contract most, and so become concave. It is obvious that these curvatures will be produced with less strain and be more perfect if there be introduced between the two metals a third of intermediate expansibility. In Breguet's thermometer or pyrometer, a slip of gold is interposed between 2 slips of platinum and silver, and the combined layer is then drawn to a great degree of thinness, being only $\frac{1}{1200}$th of an inch; after which it is curved into the spiral form, as in Fig. 2164, with an index at the bottom turning round a graduated circle. When this coil or spiral is heated, it tends to unbend, and this is rendered perceptible by the lower end, to which the index is attached, moving slowly round to accommodate itself to its less curved state; and thus the degree of unbending may be measured with the aid of the graduated circle.

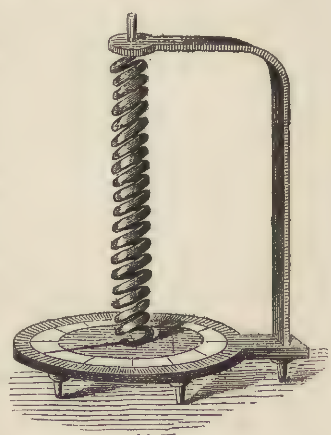
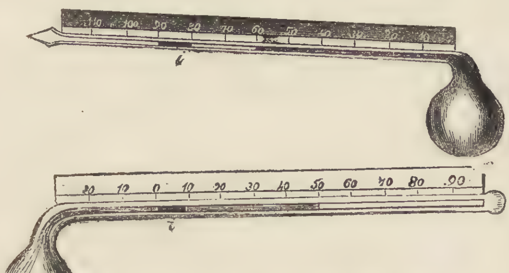


Fig. 2164. Breguet's pyrometer.

Thermometers of various constructions have at different times been invented for marking the highest and the lowest degrees of temperature which may occur in the absence of the observer. Such instruments are called *Register Thermometers.* The *Day and Night Thermometer* of Dr. John Rutherford consists of a mercury and a spirit thermometer, each provided with its own scale. The stems are placed horizontally, or at an angle inclining a few degrees upwards, and the bulbs are at right angles to the stems. Both thermometers may be mounted on the same frame, or

(1) Philosophical Transactions for 1830.

they may be separate, as in Figs. 2165, 2166. To register the highest temperature between the times of observation, a piece of steel *i*, such as a fragment of a sewing-needle, is placed within the stem of the mercury thermometer, and as the mercury expands, it pushes this piece of steel before it; but if after this the mercury fall, the steel is left behind to mark the point of greatest expansion. To register the lowest temperature, a cylinder of white enamel, with a small knob at each end, is enclosed in the stem of the spirit



Figs. 2165, 2166. RUTHERFORD'S REGISTER THERMOMETERS.

thermometer; when the spirit is contracted by cold, the attraction between the last film of the column of spirit and the enamel is sufficient to overcome the slight friction of the latter on the inside of the tube, and to draw it backwards in the direction of the bulb; but if the spirit begin again to expand, it passes the enamel without pushing it forward; and the lowest degree of temperature is thus registered. To adjust the instrument for a fresh observation, it must be inclined, so as to bring the register marks to the respective surfaces of the two fluids; should there be any difficulty in this, (which there is not in a well-made instrument,) the head of the enamel furthest from the spirit may be made of steel; and then both thermometers may be adjusted by means of a small magnet applied to the outside of the stem.

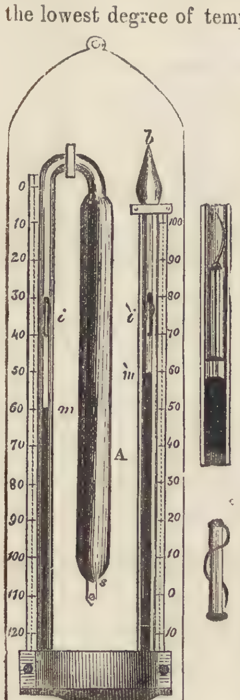


Fig. 2167. SIX'S REGISTER THERMOMETER.

In 1782, Mr. Six constructed a self-registering thermometer. It has been modified since that time, and the following is a good form. A, Fig. 2167, is a tube or long bulb, filled with alcohol, and connected by a bend with a tube *m m'* also filled with alcohol down to the point *m*, where the mercury commences; this is continued round the lower bend to the point *m'*, where alcohol again commences and continues up to the top, partly filling the bulb *b*, a portion of which is left empty to allow space for the expansion of the liquid. Two indices *i* and '*i* are immersed in the alcohol just above the surface of the mercury in the two exterior tubes. These indices are of steel coated with glass, and finished at each end with a spot of enamel. To prevent them from moving through the alcohol by their own weight, a spring of glass or of bristle is attached to them, which by being somewhat bent presses lightly against the interior of the tube, as shown on a larger scale in the figures at the side. If the highest and lowest temperatures which occur during the absence of the observer be required, he first adjusts the instrument by drawing down the indices to the two surfaces of the mercury by means of a magnet. Suppose then that the temperature increases during the absence of the observer: the alcohol in the bulb A expands and presses down the mercury at *m*, which of course occasions a rise at *m'*, by which the index '*i* is raised. Any subsequent depression of temperature will lower the surface *m*, but cannot lower the index '*i*, which clings to the sides of the tube. The greatest increase of temperature during the observer's absence is denoted by the position of the index '*i*; and a scale of degrees attached to the instrument measures that change. But if the temperature fall, the alcohol contracts; and the mercury rises at *m*, pushing the index *i* before it; from which position it likewise cannot again recede, however much the temperature may afterwards increase. A scale measures that change of position as before, and the application of a magnet will again prepare the instrument for another observation.

Other forms of thermometers have been proposed for particular purposes, of which two or three examples may be given.

Many years ago Dr. Cummings of Chester invented a thermometer for opening and shutting the door or window of a hot-house or other apartment when the temperature had attained a certain point. It consisted of a large glass or iron matrass *m* Fig. 2168 filled with air, but with mercury in its stem, which was inverted in a cistern C containing the same fluid. The matrass was connected by a cord with the sash of a window *w*, or of a ventilator V; the cord passed over pulleys *p p' p''*, and the weight of the matrass was so adjusted that it nearly balanced the weight of the sash or ventilator. When the increase of temperature expanded the air in the matrass, a portion of the mercury was driven out of the stem, so that the matrass became lighter than before, and thus not an

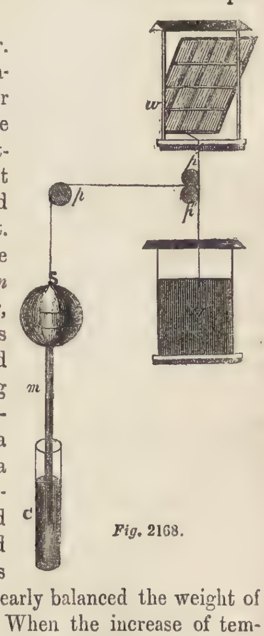


Fig. 2168.

equal balance for the window-sash or ventilator, which was thus let down from the top; and so a communication with the external air could be either established or cut off, according as the temperature of the room affected the air in the matrass. A similar principle was applied by Dr. Arnott to the construction of a self-registering stove. See WARMING and VENTILATION.

An instrument called a *thermometric alarum* was shown in Class X. of the Great Exhibition. It consisted of a bent glass tube with a bulb at each end, one of which with a part of the stem contained ether, and the other, which was open to the external air, a certain quantity of mercury, which also occupied a part of the stem. The tube was poised on its centre of gravity; but if, from any cause, the temperature should rise, as in the case of an accidental fire, the expansion of the ether would drive the whole of the mercury into the open bulb, cause it to tip over and discharge an alarum. *Balance thermometers* are by no means new. One was patented in 1816 by Mr. Kewley, and was employed to shut and open doors according to the temperature of the apartment.

We will now briefly describe the principle of the *second* class into which we have distinguished Thermometrical Instruments. Their object is to compare the total quantities of the *cause of heat*, which are given out in the cooling of known quantities of different substances through a given number of degrees, or in the chemical action of given quantities of different materials. Hence the name *calorimeter* or measurer of *caloric.*

The calorimeter, Fig. 2169, was invented by Lavoisier and Laplace. It consists of 3 concentric metallic vessels, S C E, completely enclosed one within another, and connected by as few supports as possible. When used for determining the specific heats of bodies as mentioned under HEAT, the temperature of the air must not be higher than 40°, nor so low as 32°. The two outer compartments are filled with broken ice, which is of course in a melting state, and therefore maintains a constant temperature of 32°, although constantly receiving heat both from the external air and from the innermost vessel. When therefore the substance to be examined is heated and placed in the inner vessel E, all the heat which it gives out is employed in melting the ice which immediately surrounds it; the resulting water is allowed to drain through a pipe *d* from the bottom, and being carefully collected and weighed, shows how much ice has been melted (without raising its temperature), or how much water might have been raised 140° by the cooling of the substance examined, through a known number of degrees—for no heat could penetrate to this ice from the external air, because all the heat that enters the calorimeter from without is employed in melting the ice of the *outer* vessel, which drains through a separate pipe *d'*, and is not allowed to mix with the drainage of the *inner* ice. In fact, as long as the two outer vessels are kept constantly supplied with melting ice from the top, they form a perfectly insulating wall, through which no heat can pass, for as ice cannot exist above the temperature of 32°, whatever heat enters it must be employed in melting the first layer, and can proceed no further, if that layer be renewed. The use of this instrument requires great care that the quantities of water retained in the interstices of the broken ice by capillary attraction may be equal before and after the experiment; otherwise great errors will be introduced by this cause.

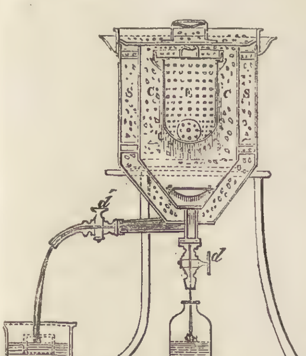


Fig. 2169. CALORIMETER.

By similar contrivances various observers have measured the relative quantities of heat evolved by the combustion of different kinds of fuel. The results are usually expressed by the number of pounds of ice that could be melted (or of water that could be warmed 140°) by the combustion of one pound of the fuel. The following table shows a few of these results as obtained by Dr. Dalton and by Count Rumford. The second column shows the weight of oxygen necessary to support the combustion of one pound of the fuel; by which it will be seen that the more oxygen is consumed, the more heat is in general produced.

Fuel of which one pound is burned.	Lbs. of oxygen consumed.	Lbs. of ice melted.
Hydrogen	8	320
Light carburetted hydrogen	4	88
Heavy carburetted hydrogen	3·5	85
Carbon	2·66	40
Wax	3·14	126
Tallow	3·1	111
Ether	2·6	107
Naphtha	3·33	97
Olive oil	3	93
Alcohol	2·1	58

The first four results, which are by Dalton, would furnish the means of calculating the heating effect of all available kinds of fuel, were it not that they were unfortunately obtained by an imperfect method, in which much of the heat was unavoidably lost. They must only be compared among themselves, therefore, being proportionally *lower* than the other determinations by Count Rumford.

It has been calculated by M. Pouillet, that the daily amount of solar heat received by the earth would suffice to melt a layer of ice averaging, over the whole earth, $1\frac{1}{2}$ inch thick. As the average weight of such a layer would be about $65\frac{1}{4}$ lbs. per square yard, it follows that the heat received daily is equivalent to that which would result from the burning of 26 oz. of carbon, for every square yard of the earth's surface; or as another illustration, the mean amount of heat radiated daily from the sun upon every acre of land in this latitude, is equal to that which would be emitted during the combustion of sixty sacks of coals.

The *third* kind of thermometers are those intended to measure *radiant heat.* In order to do this without employing *time* as an element of the observation, it must evidently be necessary to have only part of the instrument exposed to the heating rays, and part shielded from them, and then to measure the difference of temperature between these two parts. The instrument should measure this difference *only*, and should be unaffected by any change of temperature taking place in both parts equally.

The first instrument invented for this purpose was the *differential thermometer* of Leslie, represented in Fig. 2170. It consists of a glass tube, bent into the form of the letter U, with a bulb at each extremity containing air. The tube contains sulphuric acid (freezing point 0°, boiling point 605°), tinged with carmine; and it is supported on a stand, as shown in the figure.

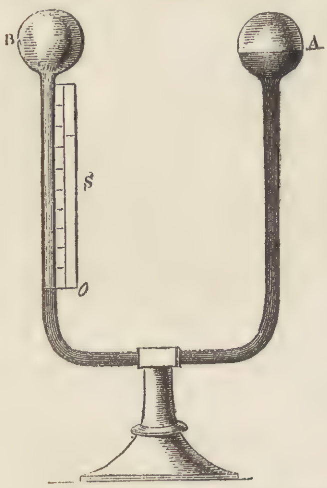


Fig. 2170. DIFFERENTIAL THERMOMETER.

In order to understand the action of this instrument, we must refer to what has been stated under AIR and HEAT, respecting the extreme compressibility of airs or gases; all of which must (in the state in which we examine them) be considered as compressed enormously, by the superincumbent weight of the atmospheric ocean. Any portion of air then enclosed in a vessel, exerts a great pressure, by tending to expand, and therefore to burst the vessel, were it not for the external pressure, which exactly counteracts this tendency. If, however, the temperature of the vessel be raised above that of the external air, although the included air cannot expand, yet the repulsive force between its particles will be increased; that is to say, its *pressure* or *elasticity* will be increased, and by exceeding that of the external air, may lead to the bursting of the vessel, as when an inflated bladder is held near a fire. The bulbs of the differential thermometer, however, are made strong enough to resist a moderate inequality between the internal and external pressures; but if, by a difference between the temperatures of the two bulbs, the expansive force of the air in one of them should exceed that in the other, the column of liquid in the tube will immediately move towards the colder bulb, till by compressing the air in that bulb, and allowing more room for the air in the warmer bulb, it has equalized their elasticity or pressure. It will therefore sink in the stem of the warmer bulb, and rise in the other stem, and the amount of this rise is measured by a scale S.

In order to render this scale as efficient as possible, the quantities of air in the two bulbs are so adjusted, that when both have the same temperature, the liquid may stand near the top of the stem of A, but near the bottom of the stem of B, to which the scale is attached, with its zero opposite the liquid surface. This instrument therefore always indicates 0° when there is no *difference* between the temperatures of the two bulbs; its chief value, in fact, depending on its total indifference to all changes that affect both bulbs alike. The scale therefore indicates only the *difference* of the temperatures of the two bulbs (whence the name of the instrument). This scale is usually divided in such a way that 10 of its degrees correspond to 1° of the French Centigrade scale, so that a rise of 10 of these degrees denotes the bulb A to be 1° Centigrade warmer than B. Of course the bulb A must always be exposed to the higher temperature, otherwise the liquid would retreat out of the range of the scale—hence A is generally called the *sentient* bulb.

It was by means of this instrument, combined with a mirror for condensing the heating rays upon the sentient bulb, that Leslie made those remarkable discoveries respecting radiant heat which have been briefly noticed under HEAT; and in order to keep the scale bulb out of the course of the rays, it was generally made to stand lower than the sentient bulb, although both are shown of equal height in the figure,—the scale bulb being there supposed to be on one side of the focus, which is concentrated on the other bulb.

M. Melloni, in pursuing the investigations on radiant heat, found it necessary to have a differential instrument for measuring very minute changes in temperature, of which the instruments before described are altogether incapable. It is obvious, that there is a large number of temperatures within the range of only one degree on Fahrenheit's, or even Leslie's scale; and analogy would lead us to suppose that there are many states of matter, inorganic as well as organic, which, if they do not absolutely depend upon such small changes in temperature, at least owe many of their modifications thereto. Our knowledge of animate nature must obviously progress only in proportion to the progression of our instrumental aids. The chrysalis of a butterfly, and the insect itself, have been proved to possess temperatures essentially different; and yet this difference is but a fraction of a degree on Fahrenheit's scale. The means for determining so simple a fact as this must be invaluable to the natural historian; and such means we will briefly indicate.

The *Thermo-Multiplier* is an instrument contrived by Nobili and Melloni, for measuring small quantities of radiant heat, by means of the electric currents which are excited when metallic bodies are unequally heated. These *thermo-electric* currents (as they are called) are always extremely feeble, even when the difference of temperature between different parts of the metal is considerable, and they are feebler in proportion as that difference is less; but there is hardly any limit to the delicacy with which we may detect electric currents by their magnetic effects. The

effect of such currents in disturbing the position of a magnetic needle [see Electric Telegraph] is *multiplied* by making the current pass many times in the same direction; thus when the conducting wire is coiled into a spiral form or *helix*, each turn adds to the effect on the needle. On this principle is constructed the instrument called the *galvanometer*, the delicacy of which depends on the number of turns in its wire, and may therefore be increased almost without limit.

Melloni's heat detector consists of a galvanometer, *g* Fig. 2171, so arranged as to receive and measure the

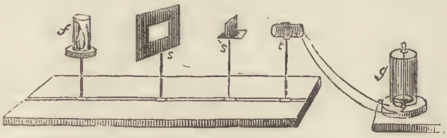


Fig. 2171.

electric current excited in a thermo-electric pile or battery *t*. This battery is constructed on the principle that in some metals, when unequally warmed, an electric current flows from the hotter to the colder part; while in other metals the reverse is the case. The former kind of current is excited most powerfully in *bismuth*, while the latter property exists most decidedly in *antimony*. The pile or battery, therefore, consists of 36 small slips or bars of antimony, and the same number of bismuth, all packed together and enclosed in a ring, so as to form a bundle or faggot, little more than an inch long. The two faces of this bundle are made flat, and the bars so soldered together, two and two, at their ends, as to form one unbroken connexion from the first bar to the last, from which two bars the wires proceed to the galvanometer. The bars are kept from touching, except at their ends, by some non-conductor of electricity, (as silk or resin,) and the ring is also made of non-conducting material. The two ends or faces of the bundle are covered with lamp-black, that they may freely both receive and emit radiant heat; and whenever the temperature of either of these faces is raised above or cooled below that of the other, an electric current flows through each antimony bar, from the cooler to the warmer end, and through each bismuth bar in the contrary direction, so that all these currents combine to form one general flow, setting from the galvanometer through the first antimony bar, back through the second bar (of bismuth), forward through the next bar (of antimony), and so on alternately to the last bar, from whence it returns to the galvanometer. The advantage of this contrivance is, that degrees of heat so small as to be quite inappreciable by the most delicately constructed thermometers, are multiplied, as it were, by the multiplication of the number of pairs of metal bars, and again by the turns of the spiral wire, and thus produce a sensible effect on the galvanometer-needle.

By means of a joint, properly situated, the axis of the pile can be placed at various inclinations, so as to point towards the object whence the rays that are to be observed proceed; and, in order to exclude all the rays that may come from other objects, the pile is enclosed in tubes of metal, which are blackened within, and polished without so as to reflect away the oblique rays.

By the aid of the thermo-multiplier, many important results have been obtained in the examination of organic and inorganic nature; as also in the consideration of various problems connected with geology, physiology, and natural history. The instrument is said to have detected the rays proceeding from a warm hand, at the distance of thirty feet.

We will give a few examples of the application of this instrument, illustrative of the action of heating rays upon certain substances. Let the source of heat be the flame *f*, Fig. 2171, and let the heating rays pass through the perforation in a screen *s*, and fall upon the substance under examination, which is mounted on a stand *s'*. The thermo-electric pile *t* will cause the galvanometer *g* to indicate the action of the calorific rays on the substance on the stand. In this way Melloni found that heat which has passed through one plate of glass is less susceptible of absorption in passing through a second plate. Of 1,000 rays of heat from the oil lamp *f*, 451 were intercepted in passing through 4 equal plates of glass, of which 381 were intercepted by the first plate, 43 by the second, 18 by the third, and 9 by the fourth. It was also found that radiant heat will pass freely through certain transparent bodies, while other bodies apparently of equal transparency resist its passage. Bodies which transmit rays of light are called transparent, or *diaphanous;* those which transmit rays of heat are termed *diathermanous;* but it does not follow that those bodies which transmit luminous rays also transmit heating rays. Rays from different sources of heat appear to have different properties; or, in other words, as there are varieties of light, distinguished by different colours and refractive powers, so there are different kinds of radiant heat varying with the source from which it emanates. The following table states the number of rays transmitted by certain substances when the source of heat was, *first* an oil flame, *secondly* red hot platinum, *thirdly* copper heated to 732°, and *fourthly* a thin copper vessel blackened on the outside and filled with boiling water:—

Substances interposed of the common thickness 0·102 inch.	Transmission of 100 Rays of Heat from			
	1. Naked oil flame.	2. Red-hot platinum.	3. Copper at 732°.	4. Copper at 212°.
Rock-salt, transparent and colourless	92	92	92	92
Fluor spar, ditto ditto	78	69	42	33
Rock-salt, clouded	65	65	65	65
Beryl	54	23	13	0
Fluor spar, greenish and transparent	46	38	24	20
Iceland spar	39	28	6	0
Plate-glass	39	24	6	0
Rock-crystal, colourless	38	28	6	0
ditto brownish	37	28	6	0
Tourmaline, dark green	18	6	3	0
Citric acid, colourless	11	2	0	0
Alum ditto	9	2	0	0
Sugar candy ditto	8	0	0	0
Fluor spar, green, translucent	8	6	4	3
Pure ice, colourless and transparent	6	0	0	0

Rock-salt possesses remarkable properties with respect to radiant heat; it is the only substance that transmits equally the rays from different sources, and it does so in the large proportion of 92 per cent. Sulphate of copper, on the contrary, which allows light to pass, is *athermanous* or opaque with respect to heat. Rock-salt has been called the "true glass of radiant heat;" it may be cut into lenses and prisms, and used for concentrating heat, or decomposing it by double refraction.

Of 100 rays of heat from the same source it was found that water transmitted 11, alcohol 15, ether 21, bisulphuret of carbon 63, and chloride of sulphur 63. When equal plates of coloured glass were employed it was found that violet glass transmitted 53 per cent., red 47, yellow 34, blue 33, and green 26. Rays of light which have passed through blue glass will pass more readily through a second blue glass than through one of a different colour: and rays of heat which have passed through water will pass more readily through a second stratum of water than through other liquids, which in the first instance are more diathermanous than water. Hence it follows that but little additional heat is absorbed when the number or thickness of screens of the same material is increased.

We may appropriately conclude this article, on one of the most important instruments that has ever assisted the progress of knowledge and of the useful arts, with the remark of a great German philosopher, "Das Instrument macht ja das Werk nicht, sondern der menschliche Geist." It is not to the instrument that we are indebted for great discoveries, but to the genius of man, who slowly but surely gropes his way from the known into the unknown, and uses the instrument as a small means to a great end.

THIMBLE. See Raised Works in Metal.

THORIUM, Th60, the metal of an earth from a rare mineral, *thorite;* it agrees in character with aluminium. The oxide *Thorina*, ThO, has some remarkable chemical properties.

THREAD. See Cotton—Flax—Silk.

THREADS OF SCREWS. See Screw.

TIDE-MILL. See introductory remarks to Steam-Engine.

TILES AND PAVEMENTS. See Pottery and Porcelain, Sect. VI.—Roads.

TILTING. See Iron, Sect. VII.

TIMBER. See Woods.

TIMBER BRIDGES. See Bridge, Sect. IV.

TIN. Sn59. Tin is one of the ancient metals. It was known in the time of Moses, and was procured at an early period from Spain and Britain by the Phœnicians. It occurs abundantly in Cornwall, and is also found in Germany, Bohemia, and Hungary; in Chili and Mexico; in the peninsula of Malacca, and in the island of Banca. In Cornwall the tin-stone is found in veins, associated with copper ore, in granite, and slate rocks, in which case it is called *mine-tin:* it is also met with as an alluvial deposit mixed with rounded pebbles, in which case it is called *stream-tin.* Oxide of tin is also found disseminated through the rock in small crystals. The principal ore of tin is the native peroxide. The preparation of the ores for reduction is described under Metallurgy. The method of smelting will be noticed presently.

Tin is a white metal, approaching silver in lustre, but when viewed so as to exclude the white light reflected from its surface, it has a yellow tint. It has a peculiar taste, and when rubbed, or held in a warm hand, it exhales a peculiar odour. Tin is very malleable; it may be beaten out into thin sheets. Common *tin-foil* is often not more than $\frac{1}{1000}$th of an inch in thickness, and what is termed *white Dutch metal* is much thinner. The malleability of tin is increased by raising its temperature to 212°. Tin is not very ductile: when bent or twisted it emits a creaking or crackling sound, (called by the French, *cri de l'étain,* or *tin-cry,*) in consequence of the crystalline texture of the interior, the noise being occasioned by the friction of the crystals on each other: in this operation the temperature rises, and, if continued, the heat is very sensible to the hand. The tin-cry is prevented by the addition of a very small portion of lead. Tin fuses at 442° Fahr., and contracts slightly on consolidation. When strongly heated it gives off white fumes. Its density varies from 7·29 to 7·6, the lightest being the purest metal. Its specific heat is 0·05623. Tin has a strong tendency to crystallization, as may be seen by applying an acid to its surface to remove the exterior pellicle. The surface then becomes mottled in consequence of the irregular reflection of the fern-like crystals brought out by the action of the acid. *Moirée metallique* is thus produced. Tin-plate, with a somewhat thick coating of pure tin, is best adapted to this manufacture. It is well cleaned by washing its surface in caustic potash, rinsing, and drying. The acid employed is a mixture of nitric and hydrochloric in water; 2 of nitric, 3 of hydrochloric, and 8 of water, answer very well. The plate is to be slightly heated, and then quickly sponged over with the acid so as to bring out the moirée. It is then to be dipped in water, washed, and dried. If the surface has been blackened or oxidized by the acid, it may be cleaned by a solution of caustic potash. The crystals on the unprepared tin plate are usually large and indistinct; but by heating the plate up to the point of fusion of the tin, powdering it over with sal-ammoniac to remove the oxide, and plunging it into cold water, the crystals may be had small. Various modifications of the crystalline surface may be obtained by sprinkling the surface of the heated plate with water, or by holding the plate over the flame of a spirit-lamp so as only partially to fuse the tin: or by running a blowpipe flame over it. The plates are finished with a coating of transparent and slightly coloured varnish.

Tin may also be crystallized by fusion, as in the case of Bismuth, but the crystals seldom have sharp well-defined edges. Tin may also be deposited from its solutions by electric agency, in elongated brilliant prisms. The tin of commerce is never quite pure: it contains arsenic and other bodies, and it is said to be purposely adulterated with iron or lead. Pure tin is sometimes judged of by its *cry:* when impure, the sound is short, and interrupted; but when pure it is

a connected creaking sound, somewhat like that produced by sole-leather. To obtain it pure, tin filings or granulated tin must be treated with an excess of nitric acid, and the resulting *stannic acid* washed with hydrochloric acid, and then with water. The peroxide of tin thus obtained is reduced to the metallic state in a closed crucible lined with charcoal, and raised to a low white heat. Tin is not much affected by exposure to the air at ordinary temperatures, but when fused its surface becomes covered with a greyish pellicle, consisting of protoxide of the metal with stannic acid. If the temperature be raised to a white heat, tin burns vividly, and if a globule of the metal be thrown upon a sheet of dark-coloured paper, it divides into small particles which burn vividly, and leave lines of white oxide. At a red heat tin decomposes vapour of water, peroxide being formed, and hydrogen gas evolved. Water is also decomposed by tin in the presence of the fixed alkalies, and on heating it in a concentrated solution of potash or of soda, hydrogen is evolved, and a stannate of the base formed.

Strong hydrochloric acid dissolves tin with the production of hydrogen. Warm dilute sulphuric acid produces similar effects, but very slowly. Concentrated sulphuric acid acts on tin with energy, sulphate of the protoxide being formed, and sulphurous acid evolved. Nitric acid acts upon tin with great energy, as already noticed, stannic acid being formed, and nitric oxide evolved largely. But if the acid be very dilute, the gas is not given off, but peroxide of tin and nitrate of ammonia are produced.

Protoxide of tin, or *stannous oxide*, SnO, is obtained by precipitating a solution of protochloride of tin by means of ammonia: the precipitate is a hydrate; when dried out of contact with air it is of a dark colour, and is not decomposed by heat alone. It may be rendered anhydrous by heating the hydrate to redness in a retort filled with carbonic acid. It forms a dense black powder, which takes fire on the approach of a red-hot body, and burns like tinder, producing peroxide. There is also a *sesquioxide*, Sn_2O_3. The *peroxide*, also called *stannic acid*, SnO_2, is procured in two different states which have dissimilar properties. When perchloride of tin is precipitated by an alkali, a white bulky hydrate is formed, which is soluble in acids. But if the bichloride be boiled with excess of nitric acid, or if nitric acid be made to act on metallic tin, a white substance is formed, not soluble in acids, and differing in other respects from that formed by the other process. They have, however, the same composition, and, when ignited, form a pure peroxide of a pale yellow tint: they both dissolve in caustic alkali, and are precipitated by an acid. When peroxide of tin is fused with glass, it forms white enamel. [See ENAMEL.] *Tin putty*, or *jewellers' putty*, [see PUTTY-POWDER,] is probably a mixture of the protoxide and peroxide of tin.

The *protochloride of tin*, $SnCl$, is formed by dissolving metallic tin in hot hydrochloric acid. It crystallizes in needles containing 3 equivalents of water. The chloride may be obtained anhydrous by distilling a mixture of protochloride of mercury and powdered tin. Chloride of tin is a grey resinous looking body, fusible below a red heat. It is soluble in a small quantity of water, but is decomposed in a large quantity, unless an excess of hydrochloric acid be present. "This acid solution quickly absorbs oxygen, and if added to certain metallic solutions revives or deoxidizes them. It decomposes and precipitates sulphur from sulphurous acid. It reduces the persalts of iron to protosalts, and converts arsenic acid into arsenious, and chromic acid into oxide of chromium. With a very weak solution of corrosive sublimate it forms a grey precipitate of metallic mercury. Added to a dilute solution of chloride of platinum, it changes its colour to a deep blood-red. With solution of gold, it produces a purple precipitate used in painting porcelain, and known under the name of *Purple of Cassius*. With infusion of cochineal, it produces a purple precipitate; and it is much used to fix and change colours in the art of dyeing and calico-printing. The greater number of vegetable infusions are precipitated by it, in consequence of the insoluble compounds which it forms with the varieties of extractive matter." [1]

Perchloride or *bichloride of tin*, $SnCl^2$, formerly called "fuming liquor of Libavius," may be formed by exposing metallic tin to the action of chlorine, or by distilling a mixture of 1 part tin in powder, and 5 parts of corrosive sublimate. It forms a thin, colourless, mobile liquid, which boils at 248°: it fumes in the air, and when mixed with one-third part of water forms a solid crystalline mass. The dyers use the solution as a mordant, and prepare it by digesting tin filings in single aquafortis, adding 2 oz. of common salt or sal-ammoniac to every pound of the solution.

When tin is fused with excess of sulphur and the product strongly heated, *protosulphuret*, SnS, is formed; it is a lead-grey, brittle substance. By heating this with one-third of its weight of sulphur, a *sesquisulphuret* Sn_2S_3, is formed: it has a yellowish-grey colour, and a metallic lustre, and is readily decomposed by heat. *Bisulphuret of tin*, SnS_2, is prepared by exposing to a low red heat, in a glass flask, a mixture of 12 parts tin, 6 mercury, 6 sal-ammoniac, and 7 flowers of sulphur. Sal-ammoniac, cinnabar, and protochloride of tin sublime, and the bisulphuret is left at the bottom of the vessel in the form of brilliant gold-coloured scales, called *aurum musivum* or *mosaic gold*. It is much used for ornamental work under the name of *bronze-powder* [see BRONZING], especially by the manufacturers of paper hangings. It is principally imported from Holland and Germany. X

The other salts of tin do not require special notice, except that variety of the *sulphate* which is known as *Bancroft's tin mordant*. It is prepared by pouring 3 parts of muriatic acid on 2 of tin filings, and after the lapse of an hour adding carefully 1·5 parts of sulphuric acid: the tin dissolves, and the mixture is kept warm so long as hydrogen is evolved: when cold the residue is dissolved in water, poured off from the undissolved

(1) Brande: "Manual of Chemistry, 1848."

tin, and diluted so that 8 parts of the solution may contain 1 part of tin.

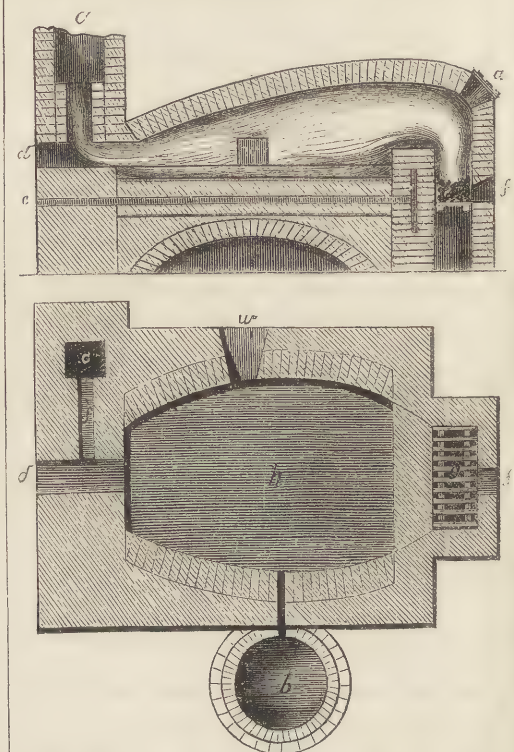
The tin of commerce is obtained from the native oxide, which in its pure state consists of $Sn\,O_2$. A specimen from Cornwall, analysed by Klaproth, gave tin 77·50 per cent., oxygen 21·50, oxide of iron 0·25, silica 0·75. The most common crystals are square-based prisms terminated by 4 triangular faces, often modified on their edges and angles. The massive varieties of oxide of tin are called *stream-tin.* When the ore occurs in reniform masses, or wedge-shaped pieces with concentric bands, which give a ligneous appearance to the mineral, it is called *wood-tin.* Stream-tin is probably derived from the destruction of tin veins or lodes; the lighter portions having been carried away by the water which rounded the fragments of the ore. See Mine—Mining, Fig. 1542.

Tin pyrites or sulphuret of tin is a scarce mineral; it has been found in Cornwall in a crystalline state in one locality only,—Huel Rock Mine, St. Agnes.

When the ores have been washed and prepared as described under Metallurgy, they are roasted to get rid of sulphur and arsenic. Reverberatory furnaces are used for the purpose, the flues of which are connected with large condensing chambers, in which the arsenic is deposited in a crystalline form. By a second sublimation it forms the white arsenic of commerce. [See Arsenic.] When the ore ceases to exhale white fumes, it is let down into an arched chamber below the furnace to cool. The calcined ore is again washed, and the impurities, which have for the most part been decomposed and converted into peroxide of iron, are removed. If the ore contains copper pyrites, it is after a careful roasting exposed for some time to the atmosphere before being again washed, in order partially to oxidise the sulphurets, and convert them into sulphates, which are soluble in water and thus more easily removed. If the tin ores contain copper, they may after roasting be treated with dilute sulphuric acid, which dissolves the copper but does not attack the tin. After washing, the ore is called *black tin,* and is ready for smelting. The method of treating tin ores which contain wolfram is noticed in our Introductory Essay, page xcvi.

The smelting of tin ores may be conducted either in a reverberatory furnace with common pit coal, the ore being mixed with powdered anthracite or other carbonaceous substance; or, where a very pure metal is required, in a small blast furnace with charcoal for fuel. The former process is conducted in what are called *smelting houses,* and the latter in *blowing-houses*

The reverberatory furnace is shown in vertical section Fig. 2172, and in plan Fig. 2173. Coal is supplied to the grate *g*, by the fire-door *f*; the ore is introduced to the hearth *h* by the hole *w*. *d* is the working door, and at *a* is a hole occasionally opened for the purpose of admitting a draught of air for carrying the fumes up the chimney during the skimming of the slags; at *c* is a channel for admitting air beneath the hearth and through the fire-bridge for moderating the heat; *b* is a basin into which the metal is drawn off; c is the chimney, which should be 40 or 50 feet high. The ore is well mixed with about ⅛th of its weight of powdered coal or anthracite, and a small quantity of slaked lime or fluor spar, to serve as a



Figs. 2172, 2173. SECTIONAL ELEVATION AND PLAN OF TIN SMELTING FURNACE.

flux for the silica present. The charge consists of 20 to 25 cwt. of ore, and contains from 60 to 65 per cent. of metal. It is slightly sprinkled with water, to make it more compact, and prevent any of it from being carried off by the draught. During the first 6 or 8 hours the furnace doors are kept closed, and the heat is gradually raised. The oxide being then reduced, the door *d* is opened, and the fused mass is worked with a long iron paddle to separate the metal from the slags, which being done, they are carefully withdrawn by an iron rake, and are afterwards divided into 3 classes,—1. Those of the first class, which form about ¾ of the whole weight produced, contain little or no metal, and are rejected. 2. Those of the second class contain small globules of tin to the extent of about 5 per cent., which are separated by washing at the stamping-mill. 3. The slags of the third class, small in quantity but rich in metal, are those scoriæ which are removed by the rake just before the metal is let out into the basin *b*: they are set aside for mixing with the next charge. The clay stopple is removed by a pointed iron bar from the channel which leads into the basin *b*, and the metal flows out, and being left for a short time any remaining slags rise to the surface and are skimmed off.

The tin is then ladled into rectangular moulds, from which it comes out in the form of blocks.

The tin thus produced is contaminated with iron, arsenic, copper, and tungsten, and also contains some oxide of tin not reduced. It is refined by two processes, the first of which is a *liquation* in a reverberatory furnace similar to Fig. 2172. The second is a species of *poling*, somewhat similar in effect to the operation described under COPPER. For the liquation, the impure blocks of tin are arranged in a sort of hollow heap near the fire-bridge, and gradually heated to the fusing point. The tin flows for some time into the outer basin, and a ferruginous dross remains in the furnace. Other blocks are put into the furnace, and the operation is continued for about an hour, until about 5 tons of metal are collected in the basin. The ferruginous residue is removed, and is afterwards treated with the slags of the second and third class of the smelting, and being all smelted together, produce tin of very inferior quality. The second part of the refining process consists in lowering into the bath of liquid metal, by means of an iron gibbet, billets of green wood, which by their rapid evolution of gas produce the appearance of boiling in the metal, and the effect is to bring to the surface a kind of froth, consisting of oxide of tin and other oxides, while the more impure and denser portions of the foreign substances subside. The froth is skimmed off and returned to the furnace, and when the operation has been continued for about 3 hours, the wood is removed and the contents of the basin left to subside. In the course of about an hour the metal forms 3 strata, of which the top stratum is most pure, the bottom most impure, and the middle of average purity. The three layers are ladled out into iron moulds, forming blocks, each weighing about 3 cwt., and being what is called *block tin*. The tin of the first stratum, or *refined tin*, is chiefly employed in the manufacture of tin-plate. The blocks from the third or bottom stratum are often so impure as to require a second refining in the reverberatory furnace.

In some cases, instead of refining by means of green wood, the operation of tossing is substituted. The men take up portions of the metal in ladles, and allow them to fall into the refining pot from a considerable height. The agitation thus occasioned produces a somewhat similar effect to the green wood.

Grain-tin is prepared by plunging blocks of tin in a bath of tin, and when it has assumed a brittle crystalline texture, it is broken up with a hammer; or the blocks are heated nearly to the point of fusion, and then allowed to fall from a considerable height; the metal thus breaks up into elongated grains, called by the French *étain en larmes*, or tears of tin; the operation may in fact be regarded as a kind of refining of fine metal.

The blast furnace is not used in this country for smelting tin ores; for although it affords a pure metal, it is more costly than the reverberatory furnace. In the latter $1\frac{1}{2}$ ton of coal is consumed for every ton of tin produced, and the loss of metal is about 5 per cent. With the blast furnace $1\frac{6}{10}$ths ton is required for every ton of tin, and the loss is about 15 per cent. In those mining countries, however, where coal is scarce and wood tolerably abundant, the blast furnace is used. Fig. 2174 represents in elevation and plan the furnace used in the Erzgebirge of Saxony. The

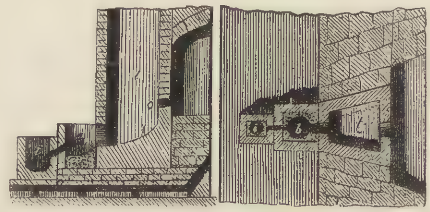


Fig. 2174. ELEVATION AND PLAN OF TIN BLAST FURNACE.

sides of the trunk *t* are of granite; the sole is also a block of granite shaped so as to have a considerable fall towards the breast of the furnace. The fused mass resulting from the reduction of the ore flows into a granite basin *b*, which is lined with a mixture of clay and charcoal; this basin communicates by a tapping hole with an iron vessel *i*. The charcoal and the ore are introduced into *t*, in charges, at stated intervals, and the combustion is urged by a blowing machine, the nozzle of which is introduced at *o*. The slags float on the surface of the metal in *b*, and are removed from time to time by an iron crook. When *b* is full, its contents are let out into *i*, and a large pole of green wood is introduced for the purpose of refining; the metal on being left to itself separates into layers of different degrees of purity. There are two classes of slags; the richer are added to the succeeding charge, and the poorer are stamped and washed for the purpose of separating the metallic particles entangled in them.

In the year ending 5th January, 1852, the quantity of tin imported into the United Kingdom in the form of blocks, ingots, bars and slabs amounted to 48,746 cwt., of which 37,727 cwt. were entered for home consumption. The gross duty received amounted to 11,331*l*.

Tin forms with some other metals alloys distinguished by whiteness, hardness and fusibility. See PEWTER—BRONZE—BRASS—SOLDER.

One of the most important of the tin alloys is that with iron in the form of *tin plate*, which unites the useful qualities of both metals. Other forms of iron are also coated with tin, to preserve the iron from rusting and staining other substances in contact with it. Many articles, such as bridle-bits, common stirrups, small nails, &c. are manufactured more cheaply than formerly, by making them of cast-iron and then tinning them. Saucepans and large pots of cast-iron are also tinned on their inner surface, which must be made chemically clean for the purpose; then heated and grain tin being poured in, the vessel is to be rolled about and the surface rubbed with cloth or tow: powdered rosin is also used to prevent the formation of oxide. Vessels of copper and brass as well as cast-iron are tinned in this way. But for many of the purposes for which tin was formerly employed, zinc is now used. [See ZINC; and for one

method of galvanising iron, see AMALGAM.] For tin-plate or *white iron*, however, the demand for tin is as large as ever. Tin-plate consists of thin sheet-iron, covered on both sides with an equable layer of tin, and worked up by the tin-man or tin-plate worker into numerous articles of culinary or domestic use. The iron used for the purpose is charcoal iron, and is rolled out to various degrees of thinness, and cut by shears into rectangles of different sizes. The sheets are arranged in *boxes*, or heaps, of 225 in each *box*.[1]

In order that the tin may perfectly adhere to the iron, the surface of the latter must be chemically clean, and the melted tin be protected from the oxidising influence of the air. A man, called the *scaler*, bends each iron plate so as to enable it to stand on edge, and then places it in a trough containing a pickle of dilute muriatic acid. In 4 or 5 minutes the plates are taken out, placed on the floor in a row, and an iron rod being under them, they are lifted up and conveyed to a furnace where they are heated to redness. This causes the oxide to scale off, and when taken out and cold, they are beaten straight and smooth on a cast-iron block. If the plates have been properly scaled they have a mottled blue and white appearance, something like that of marbled paper. The plates are further smoothed by being passed between a pair of hard polished rollers. This cold-rolling gives them great smoothness and elasticity. The plates are next immersed in an acid mixture of bran and water, one at a time, to insure a complete wetting: they are left standing on their edges for about 6 hours; then turned upon the opposite edge, and left for another 6 hours. They are then transferred to a pickle of dilute sulphuric acid, contained in a leaden cistern, divided by partitions into spaces, each of which, called a *hole*, contains a box of plates. The acid removes black spots, and makes the plates bright; but the pickling must not be carried too far, or the plates will become *stained* or blistered. Both this, and the former process with bran-water, are assisted by a gentle heat of 90° or 100°, for which purpose the troughs are placed over heated flues. The plates are transferred to clean water, and scoured with hemp and sand, after which they may be kept immersed in water during many months without rusting or losing their bright appearance.

About 5 cwt. of block and grain-tin, in nearly equal proportions, are melted in a cast-iron vessel, No. 1, Fig. 2175, and called the tin-pot. It is heated by a fire beneath, with the flue passing quite round the vessel. A quantity of tallow is added to the tin, sufficient to cover the surface to the depth of 4 inches, in order to prevent contact with the air. Another pot, by the side of the tin-pot, is filled with grease only, and into it the prepared plates are put previous to tinning. They are taken out one by one, and plunged into the tin in a vertical position to the number of 200 or 300, and are left an hour or two in the tin,

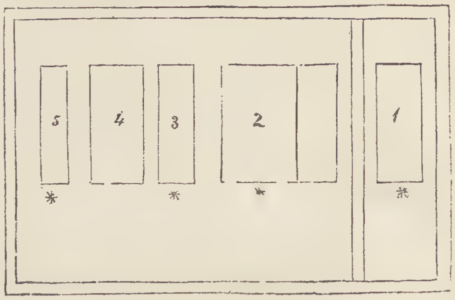


Fig. 2175.

which is kept as hot as possible without firing the grease. The plates are then taken out with tongs, and placed upon an iron rack or grating, where a considerable portion of tin drains off, but a still larger quantity is removed by the process of *washing*. The *washman* prepares an iron pot, No. 2, Fig. 2175 nearly full of the best grain-tin melted, and called the *wash-pot*; this pot is divided by a partition to prevent the dross from lodging in that part of the vessel where the last dip is given to the plates. Next to this is another pot, No. 3, called the *grease-pot;* it contains clean melted tallow or lard free from salt. No. 4, called the pan, is a pot containing only a grating at the bottom; it is for the reception of the plate when taken out of the grease-pot; this pot has no fire under it. No. 5 is called the *list-pot;* it contains only a small quantity of melted tin, sufficient to cover the bottom to the depth of ¼ inch. The building containing these pots is called the *stow*, and the plates are worked from the right-hand to the left. The asterisks show where the work-people stand.

The wash-man commences operations by putting the plates already tinned in No. 1, into the wash-pot No. 2, and the heat of the large body of tin contained in it soon melts all the loose tin on the surface of the plates, and this gradually deteriorates the quality of the whole mass, so that after 60 or 70 boxes have been washed in the grain-tin, it is usual to transfer a quantity to the tin-pot, No. 1, and replenish the wash-pot with a fresh block of grain-tin. The vessels hold 3 blocks each, or about half a ton weight of metal.

The plates are taken out of the wash-pot, a few at a time, and placed on the stow. The wash-man then takes up one plate with a pair of tongs held in his left-hand, and, with a kind of hempen brush, sweeps one side of the plate, turns it and sweeps the other side, dips it into the hot fluid metal of the wash-pot, for the purpose of removing the marks of the brush, and then into the grease-pot, No. 3. A good workman will brush and tin-wash 25 boxes, or 5,625 plates, in 12 hours. The use of the grease-pot is to remove the superfluous metal from the plates; but this requires care, because, as the tin is in a soft state when immersed in the grease, too much or too little may be removed: if too much, the plates lose their silvery lustre; if too little, the tin is wasted, and the plates

(1) The chief authority for the details of the manufacture of tin-plate is a description by Mr. Parkes, published in 1818, in "The Memoirs of the Literary and Philosophical Society of Manchester," derived from personal inspection. The manufacturers, however, affect a good deal of mystery on the subject, and the editor has never had an opportunity of witnessing the processes; but they are sufficiently intelligible from description.

are disfigured by streaks. The temperature of the grease-pot requires regulation, because, as a thick plate retains more heat than a thin one, it requires a proportionally cooler grease-pot. The grease-pot has pins fixed within it, to keep the plates asunder, and whenever the workman has transferred 5 plates to it, a boy lifts the first plate out into the cold pan, No. 4, and as soon as the man transfers a sixth plate, the boy removes the second, and so on. The plates are left in No. 4 until they become cold enough to handle. As the plates are placed vertically in the melted tin, and also in the grease-pot, there is a *list* or selvage of tin on the lower edge of each plate after it becomes cold: this is removed by dipping the lower edge of each plate into the list-pot, No. 5, which contains melted tin to the depth of about $\frac{1}{4}$ inch. When the list is melted, the boy takes out the plate and gives it a smart blow with a thin stick; this detaches the superfluous metal, and leaves a faint mark in its place, which may be noticed on every tin plate. The plates are cleansed from grease by being put, while warm, into bins of dry bran, with which they are rubbed until they become quite clean. They are then packed up in boxes, each containing a certain number of plates, according to their quality, which is distinguished by certain marks attached to the boxes, as shown in the following table:—

Names.	Sizes.	No. in a box.	Weight of each box.	Marks on the boxes.
	Inches.		cwt. qr. lb.	
Common No. 1	$13\frac{3}{4}$ by 10	225	1 0 0	CI
Common No. 2	$13\frac{1}{4}$ by $9\frac{3}{4}$	...	3 21	CII
Common No. 3	$12\frac{3}{4}$ by $9\frac{1}{2}$	...	3 16	CIII
Cross No. 1	$13\frac{1}{4}$ by 10	...	1 1 0	XI
Two Cross No. 1	...	...	1 1 21	XXI
Three Cross No. 1	...	...	1 2 14	XXXI
Four Cross No. 1	...	...	1 3 7	XXXXI
Common Doubles	$16\frac{3}{4}$ by $12\frac{1}{4}$	100	2 21	CD
Cross Doubles	...	...	1 0 14	XD
Two Cross Doubles	...	...	1 1 7	XXD
Three Cross Doubles	...	...	1 2 0	XXXD
Four Cross Doubles	...	...	1 2 21	XXXXD
Common Small Doubles	15 by 11	200	1 2 0	CSD
Cross Small Doubles	...	...	1 2 21	XSD
Two Cross Doubles	...	...	1 3 14	XXSD
Three Cross Doubles	...	...	2 0 7	XXXSD
Four Cross Doubles	...	...	2 1 0	XXXXSD
Wasters, Common, No. 1	$13\frac{3}{4}$ by 10	225	1 0 0	WCI
Wasters, Cross, No. 1	$13\frac{3}{4}$ by 10	...	1 1 0	WXI

TINCAL, an impure borate of soda. See BORAX.

TINCTURE, a solution of the active principle of a substance, generally vegetable, sometimes saline or animal. Being always more or less coloured, it has obtained its name from *tinctus*. A tincture is *simple* when only one substance is submitted to the action of the solvent, and *compound* when two or more are concerned. When alcohol is the solvent employed the tincture is said to be *alcoholic; ethereal* when sulphuric ether is used; when wine is employed the result is called *medicated wine*, and when distillation is made to assist the extraction the result is called a *spirit*. When ammonia is used in conjunction with alcohol, an *ammoniated tincture* is produced. Tinctures were formerly called *essences*, from *esse*, to be, on the supposition that the solvent took up only the purer and essential principle of the substance, rejecting the starch, gum, ligneous fibre, &c. The term *quintessence* was only a higher and purer form of essence. An *elixir* had greater consistence than an essence, and was often turbid from the suspension of extractive matter. The advance of pharmacy on the principles of scientific chemistry has discarded these latter terms, and the fancies which originated them.

In alcoholic tinctures the strength of the spirit employed varies with the nature of the substance to be acted on. A resinous body requires a strong or *proof*, or *above proof* spirit; a gummy substance a more dilute or *under proof* spirit. A tincture should be clear, and its colour characteristic of the base or active principle of the substance, and having also its taste and odour. In preparing a tincture the substance is to be bruised, and 5 or 6 parts of spirit added. The maceration should be conducted in well stoppled glass vessels for about 14 days with frequent shaking. At the end of this time the tincture is to be strained or filtered, and preserved in well stoppled dark glass vessels, not exposed to the light. Many tinctures deposit a sediment, become turbid, and undergo certain changes which interfere with their being kept. This may be prevented by first forming vegetable juices by expression of the fresh plant, allowing the feculent matter to subside by repose and the addition of alcohol 56° over proof, filtering and preserving in glass bottles as before. Tinctures are often formed extemporaneously by dissolving some of the essential oil in spirit.

TITANIUM, Ti. 24, a rare metal, named by Klaproth in 1795 after the Titans. Its oxide occurs crystallized in the minerals *titanite* or *titaniferous iron ore* and *anatase*. When titaniferous ores of iron are fused in iron smelting furnaces, small, brilliant, copper coloured cubes, hard enough to scratch glass and in the highest degree infusible, are found in the slag and in the iron which collects in cavities in the hearth, and is broken up when the stone work is renewed. It was supposed until recently that these cubes consisted of pure titanium; but they have been proved by Wöhler to consist of cyanide and nitride of titanium, and to contain 18 per cent. of nitrogen and 4 per cent. of carbon. Metallic titanium has been obtained artificially in a finely divided state. Titanic acid $Ti\,O_2$ is prepared from titanite: when pure it is quite white, and in many respects resembles silica in its behaviour.

TOBACCO. A French writer who has published a book on the cultivation of tobacco and its manufacture, states, that next to wheat, tobacco is grown in France in larger quantities than any other vegetable; and he gives as a reason the extensive consumption of snuff, cigars and tobacco among all classes of society, which so far from diminishing with the progress of civilization, appears to be largely on the increase.[1] Medical and other men have written a good deal in a general way against the use of tobacco; they have nothing very specific to urge against its use. They argue that as *nicotine*, the active principle of tobacco, is poisonous in its isolated form, the use

(1) " Nouveau Manuel complet du Fabricant et de l'Amateur de Tabac, &c. Par P. Ch. Joubert." Published among the Manuels-Roret, Paris, 1844.

of tobacco must be injurious. The experience of mankind does not confirm the conclusion, although we are bound to admit that the excessive use of tobacco, as of everything else, is injurious.

Tobacco belongs to the monopetalous genus *Nicotiana*, of which there are 40 species, most of which furnish tobacco for smoking. The word *tobacco* appears to have been applied by the Caribbees to the pipe in which they smoked the herb, while the Spaniards distinguished the herb itself by that name. The more probable derivation of the word is from a place called *Tabaco* in Yucatan, from which the herb was first sent to Spain. The name *Nicotiana* is from Jean Nicot of Nismes in Languedoc, who was agent to the king of France in Portugal, where he procured tobacco seeds from a Dutchman who had brought them from Florida. Nicot sent them to France in 1560, and from that time tobacco has been cultivated in various parts of Europe. In England its cultivation in quantities sufficient for the purposes of manufacture, is prohibited; so that with high duties, ranging from 600 to 1,440 per cent., and amounting on an average to 900 per cent., the cost of tobacco in Great Britain is excessively and injuriously high, thus giving direct encouragement to the smuggler. It is stated that in one year 70 cargoes of tobacco have been smuggled between Waterford and the Giant's Causeway, the quantity thus introduced being not less than 3,500,000 lbs.

Two principal varieties of *Nicotiana Tabacum* or common tobacco are cultivated, viz. the *Oronoco* and the *sweet-scented:* they differ only in the form of the leaves, those of the latter variety being shorter and broader than the other. They are annual herbaceous plants, rising with strong erect stems to the height of from 6 to 9 feet, with fine handsome foliage. The stalk near the root is often an inch and more in diameter, and surrounded by a hairy clammy substance, of a greenish yellow colour. The leaves are of a light green; they grow alternately, at intervals of 2 or 3 inches on the stalk; they are oblong and spear-shaped; those lowest on the stalk are about 20 inches long, and they decrease as they ascend. The young leaves when about 6 inches long are of a deep green colour and rather smooth, and as they approach maturity they become yellowish and rougher on the surface. The flowers grow in clusters from the extremities of the stalks; they are yellow externally and of a delicate red within. The flowers are succeeded by kidney shaped capsules of a brown colour, each containing about 1,000 seeds.

Fig. 2176. TOBACCO. (*Nicotiana Tabacum*)

A very large proportion of the tobacco consumed in Europe is grown in Virginia and other parts of the United States of America. The cultivation and preparation of tobacco do not greatly vary with the locality in any part of the world. Tobacco can only be grown on good rich land, and the variations in soils produce varieties in the herb. The seed is sown in nursery beds or *patches*, which are made of the best possible soil in a dry place, and so situated that they may be watered conveniently if the weather should require it. The plant beds are got ready for the reception of the seed in March or early in April; for which purpose heaps of brush-wood, straw, &c. are burnt upon the land, which is then well dug up. White mustard-seed is sometimes sown round the patch to entice the fly, which prefers mustard to tobacco. Mats must be spread over the beds on the slightest appearance of frost. In about a month the sprouts will be 4 or 5 inches out of the ground, and ready to be transplanted. The time should be selected when the ground is well softened with rain, so that the plants may be pulled up without injury to the roots. They are then removed to a field prepared by well breaking up the soil, and drawing the mould with the hoe round the leg of the labourer, so as to form a hillock as high, as his knee; the foot is then withdrawn and the hillock perfected. The hillocks are arranged in lines, 4 feet apart one way and 3 feet the other. A single root is carefully planted in each hillock, and should a shower of rain follow, most of the plants will succeed: should any fail, the farmer waits until the weather becomes showery, and supplies their place by new plants. The plants must be constantly weeded and dead leaves removed, and the soil frequently stirred about the roots. When the plants have attained the height of about 2 feet, and the flower branches begin to appear, the plants are *topped*, that is, the leading stem is nipped off with the finger and thumb-nail; otherwise it would run up to flower and seed, and so drain away much of the nutritive juices from the leaves, to increase the size of which is the object of the cultivator. After the topping, from 5 to 9 leaves are left on the stem according to the soil; but the fewer the number of leaves that are left the stronger will be the tobacco. Suckers or superfluous sprouts about the root and near the junction of the leaves with the stem must be pruned off as they arise: this process, also performed with the finger and thumb, is called *suckering*. The plant is very liable to the attacks of grubs, some of which prey on the roots and others on the leaves. They require to be gathered individually and crushed under foot. A continuance of very wet or very dry weather also produces a disease called *firing*, in which the leaves perish in spots.

When fully ripe the leaves change their colour to a yellowish green; the web becomes more prominent, and is thickened in substance. The plants must be carefully watched, and such as are ripe must be cut. If cut before they are fully ripe the leaves will not

acquire a good colour in the curing, and will also be liable to rot when packed in hogsheads. In any but intertropical climates the utmost vigilance is necessary, for should frost appear the plants are entirely destroyed. The plants are cut near to the ground, and those which have sufficiently thick stalks are cut down the middle, so as nearly to divide them, in order to facilitate the process of drying. The plants are gathered after they have been acted on by the sun for some hours. If removed from the field as soon as cut they would be broken and damaged, on account of the rigidity and brittleness of the leaves. They are conveyed to barns or *curing houses*, the sides of which admit of being partially opened to promote the free circulation of air, and within each barn poles are stretched across about 4 feet apart: the poles are connected together by cross pieces called *tobacco-sticks*, on which the leaves are hung in order to be cured. There are 3 distinct stages of these poles and sticks within the barn, besides others in the roof. The plants are suspended from the sticks 4 or 5 inches apart, with the points of the leaves downwards, the stalk of the lowest leaf serving as a hook, or the slit made in the stem of the larger plants is made to grasp the stick. The barn is thus filled from the roof downwards. The temperature of the barn must be kept tolerably uniform, and too much moisture got rid of by small smothered fires of rotten wood and bark made on different parts of the floor. In 4 or 5 weeks the tobacco ought to be *in case;* that is, when the leaves are stretched over the ends of the fingers and knuckles, they should be elastic and tough, and slightly covered with a glossy kind of moisture. The first rainy day is then selected for taking down the leaves, and the next day they are stripped from the stalks. The lower, or ground-leaves, being generally soiled and torn, are separated from the rest; while of those produced on the higher part of the stalk some are inferior to others: the leaves are therefore distributed into 3 heaps. This being done, a number of leaves are tied together at their thickest ends by means of a small leaf twisted round the others, its end being secured in a kind of knot: each small bundle of leaves is called a *hand*, and is somewhat thicker than a man's thumb at the end where it is tied. This *handling* of tobacco, as it is called, should be performed in rainy or damp weather, otherwise the leaves will crumble into dust: and if the leaves have been properly cured damp weather makes them tough. The bundles or hands of tobacco are heaped together on a wooden platform, where they undergo the process of *sweating:* this is a slight fermentation, which must not be carried too far. When carried far enough, the leaves, when stretched between the fingers, possess a certain elasticity by which the farmer knows them to be *in case* for packing. Should symptoms of decay begin to appear in the stalks in consequence of unpropitious seasons, they are stripped off before the leaves are packed. This operation is performed by taking the leaf in one hand and the extremity of its stem in the other, so as to tear them asunder in the direction of the fibre, considerable expertness being required in doing this properly. The stripped leaves are of course only made up into bundles after the stripping. If the stalks are sufficiently sound they find a ready sale, as they are used in the manufacture of certain kinds of snuff.

Tobacco is packed in hogsheads with considerable compression, so as to render it less liable to change, and less penetrable by moisture. The small bundles, or hands, are ranged one by one, parallel to each other, across the hogshead, their points all placed in the same direction. In the next course, or layer, the points are put in the opposite direction. Any vacant spaces are filled up with small bundles, so that the surface is made quite level: the thick ends of all the hands are placed nearest the sides of the cask. When the cask has been about 1-fourth filled, the *prizing* apparatus is used; this is a lever of the second kind, the fulcrum being at one end, the power at the other, and the compressing weight between the two. By means of this apparatus the tobacco in the cask is compressed into the thickness of about 3 inches. Fresh layers of hands are added, and in their turn compressed, and by repeating the operation several times, the cask is at length filled. Several casks are in operation at the same time, the packers being engaged in filling while some of the casks are under compression. The hogshead used by the Virginian planters is 48 inches long, and from 30 to 32 inches diameter at the ends, and will contain from 950 to 1,000 lbs. of tobacco.

Tobacco is cultivated throughout the East, and particularly in the northern and western provinces of India. The flavour of the Indian leaf is weaker than that of American growth, which is attributed to want of skill on the part of the curers. No plant of European introduction seems to be in such general request as this throughout India; its consumption is almost universal among the inhabitants of the Indian islands, who grow all they require for their own use, while some also export a portion. The Portuguese settlers first introduced tobacco into these islands. In 1601 the Dutch introduced smoking into Java, in the hot plains and valleys of which some fine tobacco has long been grown; but as Mr. Porter remarks, the plant "so far gives evidence of its more northern origin as to require to be first raised from seed upon the cooler mountainous tracts of the island. This circumstance occasions a peculiar arrangement: two perfectly distinct classes of husbandmen being engaged in the cultivation. The seedlings are raised and sold by the mountaineers to lowland farmers, who perfect the plants, and again dispose of the seed to the former class. This plan is found necessary to preserve the plants from degenerating, which they would do if the seed were sown at once in the hotter districts, while, on the other hand, the soil of the mountains is ill adapted for maturing the plants."[1] The land is so fertile, that the Javanese draw from it two annual crops, one of rice and the other of tobacco.

(1) The 'Tropical Agriculturist," by G. R. Porter, 8vo London, 1833.

Tobacco may be grown in all warm and temperate climates, but it succeeds better in some situations than in others. With the exception of a small spot in the island of Martinico, where that peculiar flavoured leaf *Macuba* is produced, the tobacco of Cuba is perhaps the finest in the world. Rio Negro and Cumana, also, furnish a superior aromatic tobacco. *Varinas* tobacco, grown in the Nuevo Reyno de Grenada, is in repute. The *Shiraz* tobacco, so much esteemed in the East for its delicate flavour and aromatic quality, is raised from seed planted in December in a dark soil slightly manured: the ground is covered with light thorny bushes to keep it warm, and these are removed when the plants are a few inches high. The ground is regularly watered if required, and when the plants are 6 or 8 inches high they are transplanted to the tops of ridges in a ground trenched so as to retain water. When the plants are 30 to 40 inches high, the leaves vary from 3 to 15 inches in length; the flower capsules are pinched off; the leaves increase in size until August and September, when the plants are cut off close to the root, and again stuck firmly in the ground. By exposure to the night dews the leaves change from green to yellow. When of the proper tint, they are gathered in the early morning while wet with dew, and heaped up in a shed, the sides of which are closed in with light thorny bushes, so as to be freely exposed to the wind. Here, in 4 or 5 days, the desired pale yellow colour is further developed. The stalks and centre stem of each leaf are now removed and thrown away, while the leaves are heaped together in the drying-house for another 3 or 4 days, when they are fit for packing. For this purpose the leaves are carefully spread on each other, and formed into cakes 4 or 5 feet round, and 3 to 4 inches thick, care being taken not to break or injure the leaves. Bags of strong cloth, thin and open at the sides, are provided, into which the cakes are pressed strongly down on each other. When the bags are filled, they are placed in a separate drying-house, and are turned every day. Water is sprinkled on the cakes, if required, to prevent them from breaking. The leaf is valued for being thick, tough, of a uniform light-yellow colour, and of an agreeable aromatic smell.

From the cultivation of tobacco we now proceed to notice briefly its manufacture, which varies according as it is intended to produce various kinds of tobacco for smoking, various descriptions of cigars, and different kinds of snuff. Having recently visited the Imperial Manufacture of Tobacco at Paris, we cannot do better than notice the processes as we witnessed them in that immense establishment.[1]

The store of tobacco on hand was very large, and was continually increased by fresh arrivals. We saw and examined tobacco of various growths, and could not fail to remark the different aspects which they presented. The largest proportion was Virginian, but the supply from Holland, Belgium, France, Silesia, the Lower Rhine, &c., showed that the cultivation of tobacco is by no means neglected in Europe. There was also a considerable amount of contraband tobacco, which had been seized by the Government officers, and was used chiefly for mixing with other sorts for grinding up into snuff.

Passing over the unpacking of the hogsheads, &c., the first process, called *l'époulardage*, consists in separating the hands of tobacco, rubbing and shaking them to make the leaves come apart, and to get rid of sand, dust, &c. Soiled or mouldy parts of the leaf are cut away with scissors, and the leaves are then sorted out into different baskets or boxes, according to their quality; for it is found that every hand of tobacco, although made up of leaves of nearly the same quality previous to being packed, presents different qualities after having made a long voyage, or remained compressed in the hogshead for a length of time.

The sorted leaves are conveyed into an adjoining room and sprinkled with a solution of 1 part sea-salt in 10 of water, just sufficient to remove their brittleness, and to make them sufficiently supple for subsequent operations. The salt-water goes by the name of *sauce* or *liquor*, and the operation of sprinkling, *la mouillade*. The sauce sometimes contains sal-ammoniac, sugar, and other ingredients in addition to sea salt: in this way some fancy tobaccos are concocted, and certain manufacturers in different parts of Europe make a great mystery respecting the composition of their sauce. The salt is useful in checking the putrefactive fermentation, but most of the other ingredients must be condemned as useless or fraudulent.[2] The violet colour of the *Macuba* snuff of Martinique is said to be due to the melasses contained in the sauce. Liquorice juice in which a few figs have been boiled, and bruised aniseeds added to the decoction, has been recommended as a solvent for the salt, which is to be added to saturation to the cold decoction, and a small quantity of spirits of wine added. Sea-salt is better than pure chloride of sodium for making the sauce; because sea-salt contains minute proportions of deliquescent salts, which tend to preserve the moisture of the tobacco.

(1) The French Government has the exclusive right of manufacturing tobacco and snuff for the whole of the empire. The central establishment at Paris, situated on the Quai d'Orsay, gives employment to 1500 women and 500 men. The rooms are spacious, well lighted and ventilated, and the machinery of good construction and in excellent order. It is set in motion by a steam-engine by Holcroft, of 140 horse-power. There are 10 manufactories in France, all depending on this the central one. It is stated in Galignani's Guide for 1850, that the annual profit to the State on the tobacco monopoly, is about 90,000,000 francs (£3,600,000), and that the quantity consumed, especially of cigars, is increasing. There are about 500 licensed dealers in tobacco and snuff in Paris.

(2) The various ingredients with which tobacco and snuff are adulterated in Great Britain, are enumerated in one of the clauses of the Act 5 and 6 Vict., which prohibits, under a penalty of £200, manufacturers from having in their possession, "any sugar, treacle, melasses, or honey, or any commings or roots of malt, or any ground or unground roasted grain, ground or unground chicory, lime, sand, (not being tobacco sand,) umber, ochre, or other earth, sea-weed, ground or powdered wood, moss, or weeds, or any leaves or any herbs or plants (not being tobacco leaves or plants) respectively, nor any substance or material, syrup, liquid or preparation, matter or thing, to be used or capable of being used as a substitute for or to increase the weight of tobacco or snuff."

The next operation is to remove the stalk from the leaves of tobacco: this requires some dexterity, so as not to tear or injure the leaf, and is usually done by girls. In this operation, the largest and strongest leaves are set apart by themselves, to be used as *robes* or covers for the thicker kinds of pig-tail.

Next follows a more particular sorting of the leaves, so as to bring together those portions which have the same growth and distinctive qualities. The same plant affords leaves of different colours and flavours, and it is only by a skilful sorting at this stage, that the characters of certain well-known tobaccos are preserved, or the reputation of the particular country or manufacture sustained. The tobacco thus sorted may either be cut or spun, or both. The leaves for cutting are moistened with pure water, or with a very weak solution of salt, and when sufficiently moist for the purpose, they are fed by hand into oscillating funnels, through which they pass by compression under a knife arranged very much like the knife of a chaff-cutting machine. After each ascent of the knife, the tobacco is moved forward about half a line, and the descending knife cuts off that thickness from the protruded end of the mass, and the cut fibres fall into a trough beneath. The cut tobacco is then exposed upon plates of iron heated by steam-pipes, the effect of which, assisted by an occasional rolling motion between the hands of the workman, is to make the fibres curl. When this has been carried far enough, the tobacco is removed to a heap, where it undergoes a slight fermentation, after which it is spread out and dried at ordinary or very moderate temperatures. In England what is called *bird's eye* tobacco is formed by retaining in the leaf a portion of the stalk, transverse sections of which dotted about among the fibres may remind persons of strong imaginations of bird's eyes. Shag tobacco is formed of the darkest coloured leaves, which are made darker by means of the liquor.

The other variety of tobacco, known in England as *pig-tail*, is prepared by sprinkling the sorted leaves with the sauce or liquor employed in *la mouillade*, and leaving them to ferment until the desired colour and flavour are attained. The leaves thus prepared are spun into a rope or cord at a long bench, at one end of which is a spinning-wheel turned by a boy: a second boy arranges the tobacco leaves in a line along the bench, making them overlap; a man standing between the two boys rolls up the leaves into a kind of cylinder, into which the boy at the wheel throws the desired amount of twist. When a length has thus been spun, it is wound upon a reel to be afterwards made up into balls, which are pressed, dried, and packed up for sale. The thicker kinds of pigtail are prepared by wrapping tightly and evenly round the thin cord produced by spinning the stout leaves which were set aside when the stalks were removed as already noticed.

Tobacco is sometimes imported in rolls or *carrots*, as they are called, and the carrots are also formed at the factory. For this purpose, the moist prepared leaves are placed together in large handfuls, and are wound tightly round by strips of dry fibrous wood or grass; by this treatment, the leaves become partially consolidated, and require only to be ground or rasped and sifted, to make the finest and most genuine snuff, or *rappee*, as it is called.

The manufacture of cigars is a simple operation, and at the French factory was performed entirely by women. A bundle of fragments of leaves being selected, a sound choice piece of leaf shaped like one of the gores of a small globe is placed flat on the work-bench; the bundle being placed across the centre of this gore, is rolled up in it by passing the hand flat over it; the point or nose of the cigar is shaped with a pair of scissors, and secured by means of a solution of gum and chicory; the cigar is next placed against a gage, and a portion from the broad end cut off square. We have seen cigars made by English and German workmen, and they appeared to us to produce better shaped cigars and in a shorter time than the French women, a result which we were not prepared to expect. The cigars are tied up in bundles of 25 in each, dried and kept for a time until age has sufficiently mellowed them for use.

In the manufacture of snuff, the tobacco is considerably modified by carrying the fermentation much further than in tobacco intended for smoking, and is simply ground and sifted. In the French factory, there were about 30 mills, resembling large coffee mills, or flake-cocoa mills [see CHOCOLATE, Fig. 570], only that the grinding cone to each mill instead of the usual circular motion was connected with a lever and an excentric, so as to produce half a revolution in one direction and half a revolution in the opposite direction. By this reciprocating motion, the grinding cones do not become heated, nor the teeth clogged. The ground tobacco falls upon an endless band of broad canvass, moving horizontally upon rollers, which conveys it to four sets of mechanical sieves, [see SIEVE, Fig. 1973;] the snuff which passes through is received upon an endless travelling band, which conveys it some 12 or 15 feet into a close chest, and at the turning point of this band a revolving brush sweeps off the snuff into the chest. The particles which are too coarse to pass through the sieve, escape by an opening in the frame, and are conducted by a shoot into a cylindrical trunk, in which an Archimedean screw is playing, by which means they are conducted back to the mills to be re-ground.

The immense varieties of snuffs are formed by mixing together and grinding tobaccos of different growths, and by varying the nature of the sauce. We will give one or two examples of the preparation of fancy snuffs. For the snuff known as *Maroco*, take 40 parts of genuine St. Omer (South American) tobacco, 40 parts of St. Omer (European), 20 parts of fermented Virginian stalks in powder; the whole to be ground and sifted. Then take 2½ lbs. of rose leaves, cut them and mix with powdered Virginian stalks. Add 2½ lbs. of rose-wood in fine powder, moisten with salt water and incorporate the whole well together. Then work it up with 1lb. of cream of tartar, 2 lbs. of salt of tartar, and 4lbs. of table salt. This snuff, which is highly scented, must be preserved in lead.

For *Bolongaro* take 50 parts of Amersfort leaves of the first quality, 25 parts of Virginian leaves, 25 parts of Virginian stalks. Grind the whole to fine powder and sift.

The large-grained Paris snuff is composed of 50 parts Amersfort leaves, and 50 parts of the first quality James River leaves, coarsely ground and sifted. The sauce for this snuff is thus made: dissolve 12 lbs. of salt and 4½ lbs. of soda in 12 quarts of boiling water: then boil for half an hour in a quart of pure water 2½ lbs. of tamarinds, 1 pint of red wine, 4 lbs. of sirup of sugar, 1 pint of Cognac brandy, then mix the whole with the former solution. This tobacco is ready for use in 6 months.

The manufacture of tobacco in Great Britain does not greatly differ from that of other countries; but as the duties are so excessively high, the importer examines his tobacco in the bonding warehouses of the London Docks, and removes any portions which, from defective packing, or from the action of sea-water, &c. may have become injured. The damaged portions are burnt in a furnace, familiarly known as "the Queen's tobacco-pipe;" the sound portion is weighed and returned to the hogshead, and the duty is charged on this portion only.

In the Great Exhibition, tobacco, both raw and manufactured, was well represented. Mr. Benson's cases "contained an epitome of the London tobacco trade; and among them a box of Havannah cigars ticketed 'Flor de Cabanas, Partagas and Martinez manufacture,' stands preeminent for evenness and perfection of manufacture. The variously sized, coloured, and formed cigars, in one box are stated to be all the produce of the same crop of tobacco; differences of colour and strength, and in some degree of aroma, also depending upon the age of the leaf employed and its position on the plant, the oldest or lowest being used for the well known (and extensively counterfeited) flat oily cigars called *Bravas*.[1]" Among the American varieties was the *Mason county* leaf, which produces *shag* tobacco; the thin delicately flavoured mild *Ohio* leaf, which furnishes the mild Kanaster; the *Virginian* leaf, from which common strong *ship's* tobacco, used in the Royal Navy, is manufactured. *Hungarian* tobacco, scarcely known in Great Britain, of a fine and peculiarly delicate flavour, superior to *Turkish*, was also exhibited. Messrs. Lambert and Butler exhibited a specimen of English grown tobacco: it was raised on a poor light soil in Cambridgeshire; it was of excellent growth, but deficient in flavour. Messrs Richardson of Edinburgh had fine samples of pig-tail and twist tobacco, the usual form in which the leaf is used in Scotland both for chewing and smoking.

In noticing the tobacco from the East Indies, "the Jury regret not having found samples of Awallan and various other raw tobaccos, raised in different parts of our Eastern possessions; or of the *Lunka cheroots* made from tobacco grown on the banks of the Godavery and Mahanuddy rivers, where its cultivation and manufacture are rapidly increasing, and the cheroots are superior to any others from that part of the world." The most important exhibition of German tobacco is that from Mannheim. That sent by W. Jachs is pronounced superior in flavour and in point of curing to any European tobacco known in the English market. "The Agricultural Society of Baden has encouraged the culture of this crop, which has rapidly increased to 200,000cwt. annually grown on the banks of the Rhine. The cultivation is carried on by small proprietors, and employs 20,000 hands; and the produce is sold at a very cheap rate. It is exported in leaf in vast quantities to England, Belgium, Spain, and in bad seasons to the Havannah itself: and the cigars are consumed in the United States to a great amount. Great attention is paid to the selection of fine covering leaves, upon the goodness of which the burning and drawing so materially depend." * * "The Spanish department excels all other in the beauty and variety of its cigars. The best Havannah tobacco farms are confined to a very narrow area on the south-west of Cuba. This district, 27 leagues long and only 7 broad, is bounded on the north by mountains, on the south and west by the ocean, whilst eastward, though there is no natural limit, the tobacco sensibly degenerates in quality. A light sandy soil and rather low situation suit the best." Some of the best cigars exhibited, named *Ramas*, the best that can be produced, fetch 30*l.* per 1,000 in the Havannah. They were extremely fine in flavour, perfect in burning, and so tightly rolled as to draw with difficulty, which is considered by the Spaniards as an advantage in this variety of cigar. The Spanish department also contained a few *Manilla cheroots*, and some beautiful samples of the Manilla leaf from the three principal districts of the island, Visagas, Ygarotes, and Cagayan. Portugal had also a good exhibition of tobaccos and snuffs. There was also a large assortment from Algiers, which is becoming the great tobacco mart of France. The Turkish collection of *bazaar* tobaccos was extensive, the samples particularly fine and abundant. "*Latakia* of the best quality is exhibited here, dark in colour and of a good tarry flavour. The *Moldavian* tobacco is also particularly fine." Persia exhibited the celebrated *Aburika* or "Father of Perfumes," in two samples, "one, the ordinary dark-coloured, in leaf; the other, loosely twisted into a roll, is paler, more prized in the country, and given as presents among the nobles. It is much too mild for appreciation in England, however delicate the flavour. The *Damascus* tobacco is of the same quality as the celebrated *Shiraz*, pale-coloured, but rather thick and firm in the leaf, and very strong." Russian-grown tobacco is referred to as being "very mild and rather sweet-flavoured, though not equal in aroma to the Havannah cigarillas." The exhibition from the United States of America "is chiefly of *Cavendish* tobacco, and is both extensive and admirable; the contributions of many makers attesting the importance of the manufacture and the prevalence of chewing, for which these are principally used in the United States; whilst in England they are most prized

(1) Jury Report, Class II.

as the strongest and best flavoured for smoking. The finest Virginia leaf is used in the manufacture, which consists chiefly in curing and pressing the leaf into flat square cakes of various sizes, a little molasses or sugar being sometimes added."

The importation of tobacco into the United Kingdom for the following years is thus stated:—

	Imported.	Entered for home consumption.
1849	42,098,126 lbs.	27,480,666lbs.
1850	35,162,099 ...	27,538,104 ...
1851	31,049,554 ...	27,853,253 ...
1852 Unmanufactured Tobacco	31,061,953 ...	27,853,390 ...
1852 Manufactured and snuff	2,331,886 ...	209,588 ...

The gross amount of duty received on these two quantities in 1852, was 4,386,910*l.* and 98,858*l.*

TOBACCO-PIPE. See POTTERY AND PORCELAIN, Sect. IV.

TODDY. See COCO-NUT TREE—SUGAR.

TOLU, a balsam, the produce of a tree, *Myrospermum toluiferum*, growing on the mountains of Tolu and Turbaco, and on the banks of the Magdalena. Incisions are made in the bark, and the balsam exudes during the heat of the day. It is collected in earthen crocks and calabashes; but it is often imported in tin canisters. It is soft and tenacious when fresh, but hardens in the course of time: it is translucent, brown, fragrant, and has a slightly sweet taste. It fuses and takes fire when heated, and exhales an agreeable odour. Tolu resembles Peru balsam, and consists of cinnaméine, cinnamic acid, and resin. By dry distillation, Tolu balsam yields benzoic acid mixed with a little cinnamic acid, and a yellow liquid, probably a mixture of *toluole* ($C_{14}H_8$) and benzoic ether.

What is called *black balsam of Tolu* is said to be procured by boiling the resinous bark and branches of the tree. Both kinds are much adulterated with the turpentines, copaivi or volatile oils. See BALSAM.

TOMBAC is one of the alloys of copper and zinc, containing a larger proportion of copper than exists in brass, and made by fusing copper with brass. *Dutch-gold*, *Similor*, *Prince Rupert's metal*, and *Pinchbeck*, are alloys similarly produced. See BRASS.

TONKA-BEAN, the fruit of *Coumarouna odorata.* It yields a camphor named *Coumarino*, or Coumarylic acid, $C_{18}H_7O_4$.

TOOL. See MACHINE—ENGINE.

TOPAZ. The topaz is found in primitive rocks in Cornwall, Scotland, Saxony, Siberia, Brazil, and other parts of the world. The following analyses are (Nos. 1 and 3) of Saxon topazes, and (Nos. 2 and 4) of Brazilian topazes:—

	(1.)	(2.)	(3.)	(4.)
Silica	35	44·5	34·24	34·01
Alumina	59	47·5	57·45	58·38
Fluoric Acid	5	7·0	7·75	7·79
Oxide of Iron	...	0·5	...	...
	99	99·5	99·44	100·18

Brazilian topazes are of a yellow, a blue, or a white colour; the first is the best known, and the last is more commonly termed *Mina Nova,* from Minas Novas, the name of the place which produces the finest crystals for the lapidary. The oriental topaz is a yellow variety of SAPPHIRE. For the purposes of jewellery the colour of the topaz is often changed by the action of heat. The Brazilian topaz assumes a pink or red hue so much like the Balas ruby, that it is only distinguishable by the facility with which it becomes electric by friction. Topaz pebbles are sometimes called *gouttes d'eau*, or "drops of water," from their peculiar limpidity; and when cut with facets, and set in rings, they may be mistaken by day for diamonds. The topaz is usually cut in the form of the brilliant or table, and is set with gold foil or *à jour.*

In the Russian department of the Great Exhibition was a beautiful stone labelled *Phenakite;* it was of a bluish colour, and very brilliant. Various opinions were pronounced respecting it: it was thought to be a beryl, an aquamarine, or a topaz. The owner was willing to test its hardness by scratching, but at the suggestion of Professor Tennant it was decided, as the safer test, to take its specific gravity. This was accordingly done, and on comparing it with a topaz in its natural state, the result was precisely the same, viz. 3·5, whereas the specific gravity of phenakite[1] is 2·7.

TORSION. See ELASTICITY—STRENGH of MATERIALS.

TORTOISESHELL. The covering of a marine animal, *Testudo imbricata*, or the hawk's-bill turtle or tortoise, a native of the torrid zone. The back, in this species of turtle, is arched over with a beautiful variegated substance employed in the arts as a material for combs, work-boxes, tea-caddies, cabinets, spectacle-cases, &c. This substance is formed in plates or layers, 13 in number, which overlap each other, and are surrounded by 25 much smaller plates, forming the margin to the shell. Less beautiful plates cover all the turtle species, but these generally ad here to each other at their edges; whereas, in the tortoise, they are imbricated, falling over each other like the tiles of a roof. The size and thickness of the plates, technically called *blades*, vary with the age of the animal: a new layer of horny substance is produced every year, and thus each plate, at its exposed edge, marks the age of the tortoise. At its full growth, this animal measures about 3 feet, but instances have occurred of its reaching 4 or 5 feet. The belly plates of the tortoise, which are not variegated, but plain yellow, are sometimes sufficiently clear to be made use of. Among the back plates there is also much diversity in shade, colour, and marking. The rich dark-brown shell, with occasional markings of golden-yellow, is the most prized in the market, but there is also a demand for the lighter varieties, some of which are very elegant. Some parts of plates, or particular varieties, present an almost uniform tint, so that combs of a light red, or pale-yellow or brown, may be manufactured almost without sign of variegation. Such combs are greatly prized, it appears, by Spanish ladies, who will give double

(1) Phenakite or Phenacite is a variety of Chrysoberyl, and contains silica 55·1, glucina 44·5, with a trace of magnesia and alumina.

the price for a plain comb which they would give for a mottled one. In this country plain shell is little used except for inferior purposes; and there is a shell almost colourless, which is used for covering the works of the better kind of musical snuff-boxes. To the same purpose is also applied the belly-plate of the turtle, which is less transparent than tortoiseshell. The term *shell* is, as we have already stated, [see HORN,] inappropriate to the covering of the tortoise, which consists of a layer of gelatinous matter formed on the bony arch of the back, and answering to the epidermis in other animals. When this substance is examined under the microscope it presents a series of flattened cells, which, however, may be dilated to a spherical form under the influence of a solution of potash and heat.

Some of the finest tortoiseshell is obtained from Manilla, and from Singapore: the West Indian varieties are large and heavy, but not often so beautifully coloured. Some very fine specimens from Ceylon, from Labuan, and from Trinidad, appeared in the Great Exhibition of 1851. Tortoiseshell is liable to much injury from the attachment of limpets, barnacles, &c., to the living animal: this hinders the growth of the shell at that particular spot, and causes an appearance on the shell known among dealers as *scabby*, which destroys its value.

The method of detaching the tortoiseshell from its bony axis is not, as in the case of horn, by a slow process of maceration in water, it is simply effected by placing the shell over a fire, which soon causes the plates to start away from the bone, the separation being assisted by a thin knife.

The preparation of tortoiseshell for the purpose of the manufacture is similar to that of horn; it is softened in boiling water in the same way, but with greater care, as too much boiling destroys the beauty of the colours. An addition of common salt to the water prevents in some degree this injury; but here, again, caution is needful, as too strong a brine is apt to make the shell very brittle. Tortoiseshell possesses the useful property of *welding*. Pieces of shell can be perfectly united, by scraping and thinning down their edges, and then overlapping these edges, and fixing the shell in a screw press. The press is put into boiling water, and tightened from time to time. In this way, in the course of a few hours, and without injury to the colours of the shell, the joining is effected. The same result may be obtained by the dry heat of tongs or irons; this is a quicker process, but requiring more care, or the colours will be spoiled. For small joins, a pair of tongs with flat ends will answer the purpose. The slips of shell to be joined are filed down to a very thin edge, the one on the upper, the other on the lower surface; if the join is to occur in the curved part of the intended object, the slips are dipped in boiling water, and bent to the required form; the surfaces are then united, and held firmly between the finger and thumb, while the piece is dipped in cold water to make it retain its form. The faces of the joint are then slipped asunder and filed once more, to remove any grease, which would prevent the union of the parts. A bit of clean damp linen folded many times is then placed each side the joint, to preserve it from the direct action of the hot iron, and the whole is then inserted between the tongs, which have been previously made hot enough to colour writing-paper yellow. These are now fixed in the jaws of a common vice, and moderately tightened. The work may be left to cool in the vice or it may be dipped in cold water. For larger works, a flat iron may be employed to give the required heat, moistening the shell at intervals to prevent burning, but the dry heat of the iron deepens the colour greatly, and sometimes makes it quite black.

The methods and machinery employed in making tortoiseshell and other combs have been described under COMB. It has there been shown that great economy in the use of this valuable material is effected by cutting two sets of teeth at once. A similar care to avoid waste is shown in making spectacle-frames and eye-glass frames. Formerly these were made by cutting a circular hole in the tortoiseshell of the size to be occupied by the glass; and the waste disks were laid aside to be used as occasion might offer in inlaid boxes, &c. The outer part of the frame was then shaped with saws and files. This evidently required a piece of tortoiseshell as large as the whole frame; whereas at the present day in all ordinary frames a narrow piece of the material is cut, and two slits are made in it with a thin saw. When the shell is softened by heat, these slits can be pulled out into circular holes and fashioned to the appropriate form. The groove for the edge of the glass is cut with a small circular cutter, about half an inch in diameter, and the glass is slipped in when the frame is expanded by heat. This is only one out of many instances in which the flexibility of tortoiseshell is turned to economical account; it also accounts for the slightness and brittleness of modern articles in tortoiseshell compared with those of older date. All this pulling and straining of the material obviously economises it at the expense of strength and durability.

Tortoiseshell boxes and other moulded works are largely made, and require the use of a copper, a trough for cold water, a press, moulds, &c. The mould for a round box is a wrought-iron cylinder, turned to the diameter of the box. It stands on a plate of the same, and is provided with several accurately fitting pieces of brass, which form the dies, either plain or engraved, which are to give the desired form and surface to the box. In the best kind of boxes the cover and the bottom are each made of a single leaf of shell: this is cut out in a circular form as much larger than the size of the box as the vertical height in addition to the diameter. Thus a box of three inches diameter and one inch depth, would require a piece of shell four inches in diameter for the cover, and another piece five inches in diameter, for the bottom. The round plate of shell is first laid on the top of the cylindrical mould. A small round edge block is then pressed slightly upon it; the whole is lowered into boiling water, where in 20 or 30 minutes the tortoiseshell becomes so soft that the

block can be pressed into the mould, carrying the tortoiseshell with it, and moulding it into a saucer shape. The process is repeated with different dies to give the exact form required, and the work is afterwards completed at the lathe. Inferior boxes can be made by carefully fitting together with the file fragments of tortoiseshell having bevelled edges. These are arranged along the bottom and up the sides of the mould, or they can be made into a flat plate in the first instance, and then made into a box by the process just described; but the joints in such boxes are nearly always visible.

Even the fine dust and filings of tortoiseshell are used by our ingenious neighbours, the French, in making boxes. The filings are sifted, softened, moulded, and formed into inferior and nearly opaque boxes, which often have a thin hoop of good tortoiseshell inserted in the mould to form the rabate of the box, and so improve the general appearance. Sometimes the shavings are mixed with mineral colouring matters to imitate lapis-lazuli, granite, and other stones. This kind of manufacture is almost unknown in England, where tortoiseshell boxes are usually veneered upon a body of wood, the plates being reduced to uniform thinness, and glued on as in other kinds of veneered work. But that the shell may not lose any of its effect, it is rubbed at the back either partially or entirely, according to taste, with a mixture of rich colours in fish-glue: this serves to hide the wood on which the veneer is to be placed, and also artificially enhances the brilliancy of the tortoiseshell. When a surface of tortoiseshell has to be inlaid with mother-of-pearl, gold, silver, &c., the ornaments are arranged in the required form on a plate of tortoiseshell, which rests on a bed or cushion of tortoiseshell filings within the mould, a thin paper keeping the filings from adhering to the plate. The top die plate is then steadily lowered, the mould is placed in the press, and the whole is plunged into the copper for an hour, when it is examined to see that nothing is misplaced. It is again returned to the copper for a time, and then powerfully pressed by the force of three men, and while still under pressure, it is plunged into cold water. A beautiful inlaid plate is thus formed by pressing the pearl, &c. into the very substance of the shell. This is now fit to be smoothed, and glued on to the surface of the box or other article to be veneered. Hollow walking-sticks are made of tortoiseshell, and in the British Museum is a tortoiseshell bonnet.

TOUCH-NEEDLES. See Assaying.

TOW. See Flax.

TRAGACANTH. See Gum.

TRASS. See Mortars and Cements.

TREACLE. See Sugar.

TRIPOLI, a fine grained earthy deposit, with a dry harsh feeling, and a grey, yellow, or red colour. It contains 81 per cent. of silica, mostly derived from the casts or skeletons of infusorial animalculæ, 1·5 per cent. of alumina, 8 per cent. of iron, sulphuric acid 3·45, and water 4·55. The forms of the animalculæ are readily distinguished by the microscope, and their analogies with living species may be traced: in many cases, according to Ehrenberg, the petrified appear to be identical with the living. The species are distinguished by the number of transverse lines on their bodies: the length is about $\frac{1}{288}$th of a line. Tripoli was first brought from Tripoli in Africa as a polishing material, but has since been found in France, Italy, Germany, and other places. *Red Tripoli* is prepared in large quantities from a brick earth found near Battle in Sussex. When burned in lumps it is as heavy as emery stone; it is then ground and sifted, and resembles crocus, only coarser: it is used for similar purposes. A red tripoli is also prepared by calcining and pulverizing the *clunch* or *curl stone* of the coal and iron districts of Staffordshire, formerly used only for mending the roads. It is composed of iron, alumina, lime, and silex. Clunch resembles the septaria nodules, used as the basis of Roman cement. [See Mortars and Cements.] Mr. Gill says, "the polishing effects of the calcined and pulverized clunch are superior to those of the septaria when prepared in a similar manner; and are indeed, in point of quickness of action in producing the polish, and in the beautiful black lustre which it gives to the gold or silver, far beyond anything I have ever met with."

Yellow or *French Tripoli*, as it is called, is used for the general purposes of polishing. It is also used for polishing light-coloured woods that would be stained by the absorption of darker powders into their pores. A large quantity of fine yellow tripoli was obtained in digging the canal in the Regent's Park, London. See Rotten-stone—Grinding and Polishing.

TRITURATION, the process of reducing solids to powder, in order to assist solution or chemical action. It is generally conducted dry; whereas in levigation the comminution is assisted by a liquid, [See Levigation.] When the substance is ground with a muller on a porphyry or other slab, the process is termed *porphyrisation.*

The pestle and mortar are most commonly employed in trituration, but edge-rollers are often used where the pulverized substance is required daily in large quantities. [See Chicory, Fig. 566.] Grinding in steel-mills, as in the case of coffee, pepper, &c., is resorted to where practicable, and grindstones are used in reducing corn and flour.

In the laboratory pestles and mortars are of various sizes, materials, and forms. A large iron mortar with a pestle of the same material is used for breaking large lumps into smaller, and for the pulverization of ores, metals and heavy coarse substances. Smaller mortars formed of earthy materials are used for the pulverization, and sometimes the solution, of various bodies. Such mortars ought to be "so hard as to bear the blows and friction of other hard bodies for any length of time, without suffering injury or abrasion of the surface; of a uniform and compact texture; not brittle; not permitting the absorption of fluids or penetration by them; not subject to the action of acids, alkalies or other solutions; and of a

requisite capacity."[1] The manufactured substance which best combines these various qualities is Wedgwood ware; but mortars in this ware are not made of sufficient size or thickness. Probably the very best material for mortars would be porphyry; but it is very expensive to work. Some years ago a number of slabs and mortars in this material were sent from the continent; they did not find a ready sale on account of their high price; but Mr. Bell, of Oxford Street, purchased a triturating mortar, 29 inches in diameter, for 50 guineas: it has proved a valuable implement in the laboratory, resisting the action of chemical agents, and being sufficiently hard and strong to bear contusions and the rougher processes of trituration.

A good Wedgwood ware mortar should not be capable of being scratched with the edge of a piece of quartz, or flint, or steel. It should not receive a permanent stain if a solution of sulphate of copper or muriate of iron be left in it for 24 hours. On rubbing down an ounce of sharp sand to fine powder, the sand should not acquire any appreciable increase in weight. The proportionate thickness of the mortar in different parts should be somewhat as in Fig. 2177. The pestle should be of one piece, and of the same material and qualities as the mortar. If the handle be of wood and the bottom of ware, the two are apt to separate. The diameter of the lower part of the pestle may be about one-third or one-fourth of the upper diameter of the mortar. "The curve at the bottom should be of shorter radius than the curve of the mortar, that it may not touch the mortar in more than one part, whilst at the same time the interval around may gradually increase, though not too rapidly, towards the upper part of the pestle. A mortar and pestle of the relative convexity given in Fig. 2178, may, by inclining the pestle, or bringing it to different parts of the mortar, allow portions of such different curvature to be placed in juxtaposition that the intervening space shall increase more or less rapidly from the point of contact in almost any proportion; a variation which it is of considerable consequence in pulverization to obtain with facility." Neither pestle nor mortar should be quite smooth at the grinding surfaces; but the required roughness is best obtained by use. Mortars should be lipped, for the convenience of pouring.

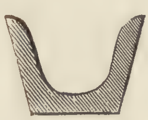


Fig. 2177.

Fig. 2178.

Small mortars and pestles are made of agate, and are useful for the pulverization and mixture of small portions of matter. They are made shallow, and are exceedingly hard. Steel mortars for pulverizing diamonds are noticed under LAPIDARY WORK, Fig. 1272.

Some knowledge and experience are required for the successful use of the pestle and mortar. Some methods of grinding or managing the pestle are for certain substances preferable to others. Some substances undergo comminution when acted on in one particular direction; sal ammoniac, for example, should have the grain upright in the mortar, not horizontal. Stony, hard substances may often be more easily reduced by igniting and then quenching in water before grinding. Charcoal may be powdered more readily when hot than when cold. Camphor is tough under the pestle, but if moistened with a few drops of spirit of wine it crumbles readily. Zinc may be powdered while hot in a heated iron mortar with a hot pestle. Some adhesive organic substances require to be mixed with clean dry sand in order to be triturated.

In the trituration of drugs a marble or Wedgwood-ware mortar is often used with a pestle of lignum-vitæ, or other hard wood. The pestle may also be of marble or stone, with a long handle passed through a ring fixed to the wall 4 or 5 feet above the mortar. Marble is objectionable for mortars on account of its being acted on by acid salts and other substances, and the surface is readily abraded. Dolomite or magnesian limestone has been recommended. Glass mortars are soft and brittle, and yield both alkali and lead to particular solvents. Mortars of wood, marble, or iron, are seldom used in the chemical laboratory.

The process of porphyrisation is used to a great extent for grinding colours. The substance to be triturated is put on the slab in the form of a coarse powder, and if unacted on by water it is formed into a thick magma therewith. It is then distributed into a thin stratum, and triturated by the muller, which is grasped with both hands, and rubbed with some pressure over the surface, following some curved figure, such as that of the figure 8, or intersecting circles; but the figures are alternated from time to time to bring fresh particles under the action of the muller. By thus extending the comminution on a very thin layer spread over a large surface, the action is more complete than with the pestle and mortar. A slate slab is sometimes used, with a large number of mullers moved in different directions by machinery, as in the manufacture of blue-pill and mercurial ointment. In the porcelain manufactory at Sèvres, a peculiar kind of mill or mortar, made of porcelain or glass, is

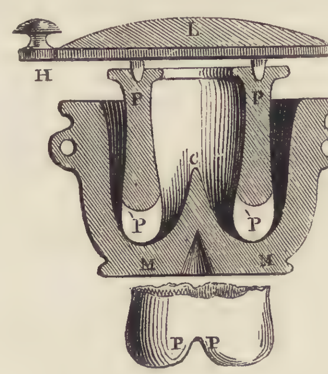


Fig. 2179.

(1) Faraday, "Chemical Manipulation," sec. v. The reader interested in the subject, will do well to study the whole of this section. He will also find further information thereon in Mohr and Redwood's "Practical Pharmacy," 1849.

used for grinding the colours. It consists of a mortar M M, Fig. 2179, with a projecting conical piece C in the centre, which forms, with the sides of the mortar, a circular trough, in which the pestle or mill P P′ moves. This pestle is a cylinder of porcelain rounded at the bottom P′ P′, as shown separately in the lower figure P P, and weighted with a disk of lead L at the top, and moved round by the handle H. This mortar acts with great expedition and effect; but M. Brongniart states that it does not produce sufficient tenuity in the colours used for painting on porcelain, for they have to be finished by porphyrisation; but in preparing for this process the mill is valuable.

TRUSSING. See CARPENTRY.

TUBES AND PIPES. The excellence which has been attained in the manufacture of certain kinds of tubes and pipes is due to a certain extent to the vast demand for gun-barrels during the late war, [see GUN,] but chiefly to the adoption of the tubular system in marine boilers. [See STEAM ENGINE.] The tubes in marine boilers are about $\frac{1}{10}$th inch thick, and as large as 3 inches in diameter when coal is used as fuel; but in locomotives where coke is burned, the tubes are only about one half the bore of those used in marine boilers. The tubes for locomotives are sometimes of wrought-iron, but more commonly of brass. Thick tubes would be too heavy either for marine or locomotive boilers. A brief notice of the more important patents that have been taken out for improved methods of making gun-barrels and gas-pipes, &c. will show the gradual advance that has been made in this important manufacture.

In 1808, Cook of Birmingham patented 3 methods of making barrels: 1. To forge a round *bar* of iron of a short length; to drill a hole in it, and to elongate the barrel by means of drawplates or grooved rollers, in either case with a mandril in the barrel. 2. To turn a short plate of iron or steel over a mandril or beak-iron, to weld it by hand, and then to elongate the barrel by drawing, &c. as before. 3. To force a circular plate of metal through a series of holes in a die, so as to raise it into a cup shape, which was to be elongated as before. None of these plans succeeded.

In James and Jones's patent, 1811, there are two methods of welding. 1. The plate of iron was turned over into the shape of a barrel with the edges in a position for welding, and a portion of the barrel being raised to a welding heat was placed on a hollow anvil having several grooves to correspond with the barrel: then by hammers worked by machinery, the heated part of the barrel was welded, a stamp or mandril being placed within the barrel. 2. It is proposed to use *grooved rollers*, the grooves being of the figures of the barrels, a mandril being used.

1817. Osborne's patent for a new method of producing cylinders.—By a previous patent the plates of iron were turned by grooved rollers ready for welding into barrels; by the present patent grooved rollers are used for welding as in James and Jones's patent, but the method of using the mandril is different A shield attached to the mandril prevented it from being drawn through between the grooved rollers in welding a cylinder or barrel on it. The unwelded barrel being raised to a welding heat, the mandril was inserted and conveyed to the rollers, the mandril being retained by stops which prevented the shield from passing; so that the barrel as it was welded by the rollers was drawn off the mandril, the mandril keeping the bore open and preventing the iron from being rolled into a solid mass. The weld was thus made, and by heating the barrel several times and passing it between grooved rollers with a succession of mandrils the barrel was drawn out to the desired length. Most of the gun-barrels of Birmingham have been welded by this plan. See GUN.

In 1824, Russell's patent for welding iron tubes by means of a hollow hammer and tool, the latter to hold the tube while receiving the blows of the former. It was found that if the tube fitted the hollow tool and hammer, no effect was produced; and if too large for the hollow the tube was crushed, and so this plan failed.

In 1825, Whitehouse suggested that a tube might be formed and welded by external pressure only, without internal support. The skelps or plates of iron being turned up into the circular form ready for welding, about half the length was raised to a welding heat, and then, by means of the chain of a draw bench, it was drawn after the manner of wire through a pair of tongs with two bell-mouthed jaws, which are opened by means of handles for introducing the end of the skelp, and then forcibly closed upon it while the draw bench did its work. Or the jaws or two halves of the die might be opened and closed by a screw. Grooved rollers capable of giving complete circumferential pressure, but with no internal supporting mandril, also fell within the claims of this simple and useful invention.

1831, Royl's patent (held to be an infringement of Whitehouse's,) was for the use of 2 grooved rollers in front of the furnace, so that the prepared tube at the proper heat should be drawn out and welded by the rollers. To facilitate the working, the upper roller could be separated from the under one, by which the tube could be moved between the rollers, and when the upper roller was brought to the lower roller and motion imparted to them the tube was run out of the furnace and welded. The tubes were then passed through dies to improve their shapes.

1836. Harvey and Brown's patent.—The mandril was a short instrument, fixed in front of the rollers, so that the enlarged head came just in the pinch of the rollers; and, in working, the heated tube was forced over the short, cranked stem of the mandril, the unclosed seam of the tube being sufficiently open to allow it to pass the fin by which the stem of the mandril was carried.

Russell's patent, 1836, was for making welded iron tubes without first turning up the iron plate, but only a few inches of the length, and then, by means of the apparatus in front of the furnace, the plate of iron at the welding-heat was first turned into the shape of a tube and welded at the same time by dyes or rollers, as in Whitehouse's patent.

Prosser's patent, 1840, for improvements in the machinery for manufacturing pipes.—It was proposed to use a combination of 3 or 4 rollers. With the latter number each roll is formed with a groove exactly equal to the quadrant of the circumferential section of the pipe, and bevelled off at 45°, so that the combination of the 4 rollers completes the circle, as shown in Fig. 2180. The 4 rollers were connected with equal wheels, so as to travel with the same velocity. The method of working was as follows:—The end of the strip of iron which was to form the tube was bent into a circle, and the strip being raised to the welding heat, the rollers carried it forward and deposited the welded tube upon a long supporting mandril, smaller than the bore of the tube, and opposite the rollers. When 3 rollers were employed, each roller included 1-third of the circle.

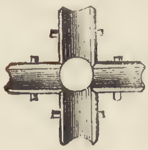


Fig. 2180.

Russell and Whitehouse's patent, 1842, for welding very thin iron tubes with scarf or lap-joints for steam-boilers.—The mandril was much smaller than the intended tube which was welded by passing the tube, with the mandril in it, Fig. 2181, between grooved rollers or through bell-mouthed dies, the hole being of an oval shape. When making the weld the mandril was set fast in the tube throughout its length; but on passing the welded tube through dies with a circular opening, the tube became cylindrical and the mandril was then readily withdrawn. The pressure of the roller or dies first acted on the outer edge of the lap-joint, then on the inner, and lastly on the central part; the three processes were accomplished at one heat, and the diametrical line upon which the pressure was applied became, for the time, the shorter diameter of the oval.

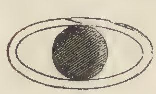


Fig. 2181.

Messrs. Russell's patent, 1844, for welding large tubes for boilers, &c., consisted of a moving hollow bed, on which the prepared tube was placed; and the bed with the tube was passed under a grooved roller. A fixed mandril was used within the pipe to give support and resistance while the roller passed over the pipe and made the weld. The end of the tube being fixed to the hollow bed, this, in its movement, carried with it the tube, and caused it to pass over the mandril and under the pressing or welding roller.

Russell's patent, 1845, for welding iron tubes.—A long fixed bar or beak-iron is supported at one end, and on this is placed the tube to be welded; the tube being at the proper heat, and the edges overlapping so as to produce a lap-joint. The weld is then produced by drawing the tube of the beak-iron under a grooved roller situated above the end of the beak-iron, which must not be less than half as long as the tube, which is welded at two processes.

Banister's patent, 1849.—Three tubes of different metals, brass, iron, and copper, are placed one within the other, the brass being inside, the copper out: a slightly tapering mandril is then introduced, and this compound tube is drawn through a series of dies until the metals are closely combined. As the metals are in a soft state when put together, it is not necessary to anneal them in the moderate drawing to which they are subjected. The benefits of this combination are, that brass is used where there is a rush of flame and the products of combustion are formed; the copper is next the water, and the whole is stiffened by the use of iron. When, however, the fire acts on the exterior of the tubes the order of arrangement must be reversed. This patent also includes a new method of soldering the joints of the tubes. The metal having been bent until the edges come together, they are filed with a triangular file into a sort of gutter. The tube is then filled with sand: it is also covered on the outside with sand, in which a gutter is made over the gutter formed by the chamfered edges: the tube is then heated to bright redness, and melted metal, similar to that of the tube, is poured into the gutter, whereby the edges of the tube are partly fused, and the whole settles in cooling into a solid mass. The projecting ridge of metal on the seam is cut off by means of a circular saw or otherwise.

The peculiarity of the modern manufacture of tubes is the absence of internal support. The mandril, which appears to be so necessary, (as indeed it is when gun-barrels are forged by the side blows of hand-hammers upon anvils or swages,) is in fact an incumbrance, for when it fits tightly it disturbs the progress of the tube over it, and spoils the work. The mandril should be used, not as a mould, but simply as a support; it should not fit the tube, but merely serve to hold it while in its heated and flexible state.

The furnace for heating the tubes is of importance: it should be of the full length of the longest tube, and be uniformly heated. The reverberatory form is generally adopted. Mr. Prosser's furnace has a door at each end for the entry and removal of the skelp, and on one side are a number of stoke-holes for the introduction of the fuel: in the opposite wall, beyond the bridge of the furnace, are corresponding apertures leading into a longitudinal chamber parallel with the fire, and thence into a lofty flue. The furnace is made to burn with equal intensity throughout its length by regulating the dimensions of the apertures. When the iron is raised to the welding-heat it must be quickly removed from the furnace, or it will be spoiled.

There is an extensive demand for brass tubes, such as are used for telescopes, which require to be very true. The brass tubes for common purposes are bent up, and soldered edge to edge, (as described under SOLDERING,) and are then drawn through a hole, which produces a roundness and smoothness on the surface, but leaves the interior rough. The tubes for telescopes are drawn inside and out through a hole in a thick draw-plate *p p*, Fig. 2182, the soldered tube being first forced upon an accurate steel cylinder triblet or mandrel *m*, and hammered into contact therewith with a wooden mallet. The steel mandril diminishes in diameter at the shoulder *s s*, and the brass tube is set or hammered down around this

shoulder. At $k\,k$ is a handle or key passing through a slot in the reduced portion of the mandrel. The brass tube being thus arranged, it is drawn by means of the key, through the draw-plate $p\,p$, the metal is

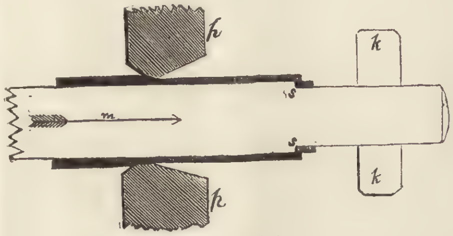


Fig. 2182.

forcibly compressed between the mandril and the plate, and thus becomes elongated as in wire-drawing. A large collection of truly cylindrical triblets are required to suit various kinds of work; and for telescope tubes, which slide within one another, there must be "a nice correspondence or strict equality of size between the aperture of the last draw-plate and the diameter of the triblet for the size next larger; and as these holes are continually wearing, it requires good management to keep the succession in due order by making new plates for the last draught, and adapting the old ones to the prior stages. Sometimes, for an occasional purpose, the triblet is enlarged by leaving a tube upon it, and drawing the work thereupon; but this is not so well as the turned and ground surface of the steel triblet."[1]

Fluted tubes for pencil-cases are drawn through ornamental plates, the mandril being usually cylindrical. Joint-wire, used by silversmiths for hinges and joints, is a small pipe threaded upon a piece of steel wire, and both are drawn together like a piece of solid wire. A semicircular channel is filed half-way in both the parts to be hinged, and short pieces of the joint-wire are soldered in each alternately. Tubes of small diameters may be completed at 2 or 3 draughts; after which, the tubes have acquired their greatest degree of hardness. The finished tube is drawn off the triblet by putting the key through one end, and drawing the triblet through an accurately fitting brass collar, which thrusts off the tube.

Tubes are sometimes drawn vertically by means of a strong chain wound on a barrel by wheels and pinions. In Donkin's tube drawing machine, a vertical screw is used, the nut of which is turned round by toothed wheels driven by 6 men at a windlass. This machine draws out cylinders for paper making, [see PAPER,] and other machines, as large as 26½ inches in diameter, and 6½ feet long.

The method of forming lead pipes is described under LEAD, Fig. 1285. In this case there is no soldered edge, which is an advantage. The brass tubes of locomotive engines are also made by casting and drawing; they are cylindrical without and taper within. The metal for them is cast hollow, and then forced on a taper triblet, and drawn through an ordinary plate. The thick end of such tubes is placed near the fire-box, in order the better to resist the action of the fire, and that the cinders which enter its smaller end may readily escape at the larger.

The remarkable ductility of tin is shown in Rand's patent collapsable vessels for artist's colours. Pieces 3 inches long are capable of being extended 36 inches by drawing them through 10 draw-plates. A tube cast ½ an inch thick and 2 feet long can thus be reduced to $\frac{1}{170}$th inch in thickness, and extended to 120 feet in length. This long tube was formerly cut up into short lengths, and the ends of each length were closed by soldering; one end with a convex disc with a projecting screw perforated for the expulsion of the colour. Each tube is now made complete by means of two blows in dies adapted to the purpose. By one blow of a screw press a thick circular disc of tin of the external diameter of the intended vessel is punched out, made concave and perforated in the centre. By a second blow the blank is converted into the finished tube. The bottom tool is a mould with a shallow cylindrical cavity of the same diameter as the tin blank, and terminating in a hollow screw: the upper tool is a cylinder longer than the tube, and with a small taper spindle of the diameter of the hole. The cylinder is just so much smaller than the mould as to leave an annular space equal to the intended thickness of the tube. The tin when subjected to great pressure in the contracted space within the mould fills up the annular crevice almost instantaneously. The tube thus formed is released from the mould, first by raising the cylinder, which leaves the tube behind, and the screwed extremity of the mould is driven up by a ram and lever from below, (as in Fig. 1819 of RAISED WORKS IN METAL, of which this may be taken as an instructive example,) and the screwed dies being divided on their diameter immediately fall away from the vessel. For large tubes the hydrostatic press is used.

The formation of cast-iron pipes falls under the general head of CASTING AND FOUNDING: this branch of manufacture, however, has of late years received many important ameliorations, which are carried out under the patents of Messrs. Cochrane and Slate, at the Woodside Iron Works near Dudley.

TUFA. Calcareous tufa is a loose porous deposit from calcareous springs. The more solid limestone formed in lakes and on the sides of hills, is called in Italy *travertin*. Many of the edifices of ancient and modern Rome are built of travertin from the quarries of Ponte Leucano. There is also a siliceous tufa consisting of volcanic material, either cinders or the comminuted lavas. Pozzuolana is a tufa of this kind. See MORTARS and CEMENTS.

TUNGSTEN, W101. The mineral wolfram is met with in Cornwall, and also a native tungstate of lime. The metal is obtained from tungstic acid, WO_3, by heating it strongly and passing a stream of hydrogen over it. It is a hard, brittle, white metal of the density 17·4. Heated to redness in the air it takes fire and tungstic acid is reproduced. There is an oxide of tungsten WO_2, but it does not form salts with acids. In our INTRODUCTORY ESSAY, p. xcvi.,

(1) Holtzapffel, "Mechanical Manipulation," vol. ii.

an outline is given of Mr. Oxland's method of dressing tin ores which contain wolfram. Wolfram is also used for making *tungstate of lead*, a pigment used instead of white lead.

TUNNEL, an arched passage underground, constructed for the purpose of conducting a canal or road on a lower level than the natural surface. Tunnels are not new in civil engineering for the Romans often constructed them to avoid the inconvenience and loss of power occasioned by conducting a road over elevated ground. The extension of canals led to the formation of many tunnels, [see NAVIGATION, INLAND;] the driving of the tunnel under the bed of the Thames was a work of unparalleled difficulty; but it is to the extension of railways that we owe the formation of tunnels under almost every variety of circumstances which are likely to occur. Tunnels have been formed in order to avoid the opposition of landowners, or to give uninterrupted passage under a road, a canal, or a river; tunnels have been formed under towns, in order to connect points which were not accessible by an open passage except at an enormous cost; but in general tunnels are formed through hills, in order to avoid the expense of an open cutting.

Tunnelling, like mining and other subterranean operations, does not derive much assistance from mechanical appliances; it is performed by hard manual labour, and is liable to unforeseen interruptions, which can only be got over at a great expense and with difficulty. Many of the old canal tunnels were executed at 4*l*. per. lineal yard; some of our railway tunnels have cost upwards of 130*l*. per lineal yard. For example, Kilsby tunnel on the London and North Western line, which was contracted for at 40*l*. per yard, actually cost 133*l*., (the contract was let for 99,000*l*. and the actual cost was upwards of 320,000*l*.) in consequence of the intersection of a quicksand which the trial borings had escaped. Pumps had to be erected to drain the sand, which extended through 450 yards of the length of the tunnel, and for 9 months 2,000 gallons of water were pumped up. The Box tunnel on the Great Western Railway cost upwards of 100*l*. per lineal yard. Bletchingley tunnel on the South Eastern Railway, 72*l*. per yard: Saltwood tunnel on the same line, 118*l*. per yard. In the latter work the tunnel intersected a great body of water in the lower green sand, so that a heading or adit had to be made quite through the hill on a level with the bottom of the tunnel, in which the water was collected and drained off. The cost of the Thames tunnel was 1,200*l*. per yard, but this must be regarded as an exceptional case; moreover it consists of 2 arches, and is in fact a double tunnel. The large sums which the above-named railway tunnels cost, ought also to be considered as exceptional; for where no accidents from water, quicksands, &c. occur, the cost is much less. For tunnelling at the ordinary dimensions in sandstone-rock, which is easy to excavate, and will stand without any lining of brick or masonry, the cost may not exceed 20*l*. per yard; but in loose bad ground, a lining of masonry or of brick-work 27 inches thick may be required throughout the tunnel, and in such case the cost may be from 100*l*. to 140*l*. per yard. Provided the stone work freely, rocky strata are generally the cheapest, on account of the absence of lining and the saving of labour by the use of gunpowder. On the Glasgow, Paisley, and Greenock railway, 314 tons of gunpowder were consumed in a length of 2,300 yards in hard whinstone, some veins of which were so hard that the rate of progress at each face of the excavation varied from 3 feet 6 inches to 6 inches per diem. Tough clay is also very difficult to remove: and the hatchet and cross-cut saw answer the purpose best. The Primrose Hill tunnel on the North Western line was excavated with great precaution, on account of the known shifting nature of the moist clay: the excavation was not allowed to be more than 9 feet in advance of the brick-work, and the clay was supported by very strong timbering, until the arches were complete. The pressure of the clay was, however, so great as to squeeze the mortar from the joints of the brickwork, and to bring the inner edges of the bricks into contact. The bricks were thus being ground to dust, and the dimensions of the tunnel were insensibly but irresistibly contracting. The difficulty was overcome by making a lining 27 inches thick of hard bricks, laid in Roman cement, which, by setting hard before the pressure became sufficient to force the bricks into actual contact, thus enabled the whole surface of each brick, instead of its edge, to resist the pressure.

Tunnels excavated in chalk are often impeded by faults or cavities full of wet gravel or sand, and the semifluid matter escapes from them as soon as they are cut into. In the Watford tunnel on the North Western Railway, which passes through the upper chalk formation, where it is covered with a thick irregular bed of gravel, fissures occur in the chalk, to the depth of 100 feet, filled with gravel, which, on being worked into, is described as rushing down "with such violence as to plough the walls of the tunnel as if bullets had been shot against it." The large ventilating shaft near the centre of the tunnel occupies the site of one of these cavities.

But of all the materials to work in, loose, running sand is the most difficult. In the tunnel on the Leicester and Swannington railway, the engineer encountered 500 yards of such sand, so that he had to construct a wooden tunnel to support the soil while the brick-work was being executed. When water occurs with loose soil the difficulties are further increased.

The Box tunnel, to which we have already referred, although excavated in rock, may be quoted as an example of difficult engineering. This tunnel, which is 3,123 yards, or a little over $1\frac{3}{4}$ miles in length, intersects oolite rock, forest marble, and lias marl with fullers'-earth. Eleven principal shafts, about 25 feet in diameter, and 4 intermediate shafts $12\frac{1}{2}$ feet in diameter, were sunk for the purpose of carrying on the works. The section of the tunnel is 27 feet 6 inches wide at the springing of the invert, and 30 feet wide

at a height of 7 feet 3 inches above this: the clear height, above the rails, 25 feet. These dimensions, however, are not strictly followed in the greater portion of the tunnel, which is constructed by mere excavation, since the clearing away of loose stone, and the securing of solid surfaces, would not admit of it. In those parts where brick-work is used, the sides are 7 half-brick rings in thickness, the arch 6, and the invert 4. During the construction the numerous fissures of the rock poured such a constant flow of water into the works, that a most extensive system of pumping had to be adopted; and so completely had the water gained over the steam-pump, that the works had to be suspended from November 1837 to July 1838: for not only was the completed portion of the tunnel filled with water, but also a height of 56 feet in the shafts. A second pump, worked by a steam-engine of 50-horse power, was applied, and allowed the works to be continued. About 32,000 hogsheads of water per day were, for some time, pumped up.

The method of tunnelling depends greatly on the kind of material to be excavated. A number of small borings is first made along the proposed line, and if these are satisfactory, shafts, at least 4 feet in diameter, are sunk along the line to the extreme depth of the tunnel: the quantity of water that appears in these, in a given time, will show how much draining-power is required. These trial-shafts should be so situated as to be convertible into working-shafts; or they may be used as ventilating-shafts. In certain cases, however, as in tunnelling near the side of a hill, horizontal galleries may be driven from the face of the hill to the line of the tunnel, and the excavated earth be removed through them. The double tunnel, through the Shakspere Cliff on the South Eastern Railway, was constructed in this way. Tunnels are also sometimes formed by means of an open cutting, and are afterwards covered in. Such are called *open* tunnels, and they are made where the object is rather to avoid the permanent severance of lands than to penetrate ground which is too elevated for an open cutting. The short tunnel at Kensall Green was formed in this way.

The usual plan, however, is by means of vertical shafts, and the driving of horizontal headings: and as the tunnel must, for obvious reasons, except in certain rare exceptional cases, be straight, and the works are proceeding not only at both ends, but also on two faces at the bottom of each shaft, it becomes a matter of paramount importance that the centre line be carefully ranged; for, by its means, the works below are corrected and ultimately made to fit together or meet into each other. The centre line is ranged by means of a transit instrument placed in a temporary building erected on some elevated spot of ground, as nearly over the middle of the tunnel as possible, so as to command a view of every shaft on the work, and at the same time be raised above the machinery and timber about the shafts, as well as the heaps of earth from the excavations. The transit instrument is supported on a brick pier, insulated from the building in order to prevent vibration. Fig. 2183 is a section of the Saltwood Observatory in the direction of the tunnel on the South Eastern Railway. The brick pier is 30 feet high: it is placed over the centre line of the tunnel, and on the top is a flat stone to which the iron stand of the transit is screwed down. The building was of timber: the upper part, or observatory-room, was enclosed with quartering and feather-edged boards. The ascent was by steps from below through a trap-door in the floor, and the floor was trimmed so as not to touch the brick pier by 5 or 6 inches. Narrow openings were made in the side of the observatory-room, through which the observer might look each way for the ranging of the lines: these holes were closed with small sliding shutters, so that one or more could be opened at a time. The building was surmounted by a two-armed telegraph, by means of which signals could be given for the ranging lines to be moved to the right or to the left, and when the line was found to be correct, both arms were extended, thus denoting that the line was to be fixed in its position as thus found.

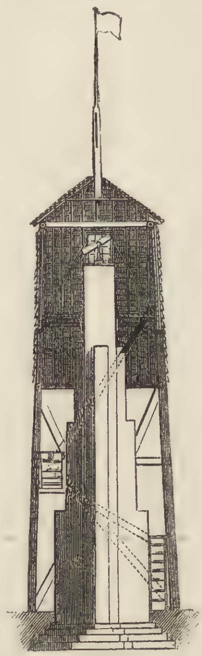


Fig. 2183.

The transit instrument consists of a telescope with an axis at right angles to its length, supported on a cast-iron stand. It is a standard instrument in every astronomical observatory, "where it is adjusted to describe or define a vertical circle passing from the north to the south points of the horizon, through the zenith of the place, and is the best means of observing the passage of the celestial bodies across the plane of the meridian, from which *time* is correctly derived: hence its name, *transit* instrument, and thus employed, it may not inappropriately be called the *hand* which points to the time as shown by that unerring dial, the starry heavens. The same construction which renders it the instrument best adapted to trace a vertical plane for astronomical purposes, makes it equally so to set out a right line on the surface of the earth; or, our problem more properly is—to find any number of points in a straight line, connecting two given distant points, the instrument to be situated also between the given distant points. The line thus connecting the distant points is the base of a vertical plane of small extent."[1] To do this, the telescope T T is made to revolve vertically on a horizontal axis A A, the

(1) "Practical Tunnelling, &c., as exemplified by the particulars of Blechingly and Saltwood Tunnels." By F. W. Simms, &c., C.E. 4to. London, 1844.

pivots of which are supported by the upright arms I I of the iron stand. It is necessary for the correct performance of the instrument that the optical axis of the telescope, or line of collimation, be precisely at right angles to the horizontal axis about which it revolves; and also that the extremities or pivots of the horizontal axis, where they rest in their bearings on the iron stand, be precisely level with each other. The telescope (as in the telescopes of theodolites and levels) is furnished with cross wires, and the intersection of the centre wires with each other represents the line of collimation when the instrument is in proper adjustment. To obtain distinct vision of the cross-wires, the eye-piece E is moved in or out by means of the screw *s*, which moves a rack and pinion. Much care is required in the adjustment of the eye-piece to the wires, and of the wires to the focus of the object glass, so as to avoid parallax, or an apparent motion between the object viewed and the wires of the telescope, which is detected by moving the eye up or down, or sideways, while looking through the telescope. In order to support the telescope without bending, the horizontal axis is made of 2 cones A A,

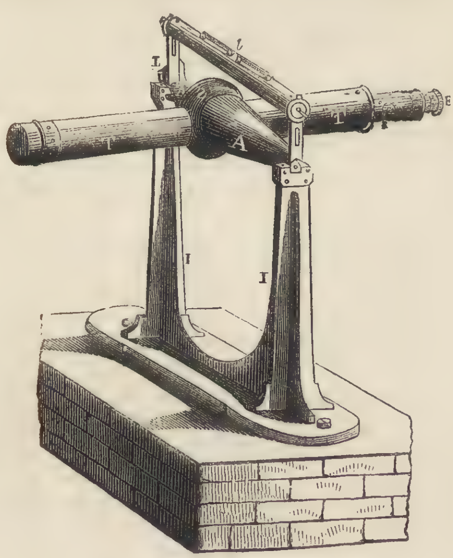


Fig. 2184. TRANSIT INSTRUMENT.

the bases of which are connected together and to the telescope by means of a sphere S, through which the telescope appears to pass. The apex of each cone has a steel or bell-metal cylindrical pivot turned and ground upon the axis as true as possible, for, unless they are true, the instrument cannot describe a vertical plane. The pivots work in Y's at the top of the upright arms I I. The spirit-level *l l*, placed across the instrument, allows the axis to be adjusted horizontal, in which position it is evident that the telescope, or line of collimation, whether elevated or depressed, or turned completely over and pointed in the opposite direction, must continue in the same vertical plane. The cross-wires of the telescope usually consist of a single spider's-thread; which, while being extremely fine, is perfectly opaque, and does not become fringed with light along its edges, as is the case with artificial substances. By day, the cross-wires are sufficiently visible, but when using the instrument underground, or by night, to range a distant light, the wires would not be visible, and the instrument would be useless. To get over this difficulty, therefore, one of the pivots is perforated through the cone A and the sphere S, and the light from a small lantern, adapted to the top of the stand, passes through such perforation, and falling on a diagonal reflector in the sphere, is thence thrown upon the focus of the instrument, where the wires are fixed, near the eye-piece. The reflector is also perforated to allow the passage of the cone of rays in their convergence from the object-glass to the focus.

Long before the commencement of working operations the direction of the centre line of the intended tunnel must be known nearly and staked out. The observatory is then erected, and a permanent mark set up at a distance from each end of the tunnel, precisely in the intended line for future reference and the occasional adjustment of the transit. At Bletchingly tunnel Mr. Simms caused to be erected 2 brick piers about 5 feet high, at the distance of full 2 miles from each end of the tunnel; such a distance secures accuracy in the adjustment of the transit, but as in foggy weather they cannot be seen, similar marks should be set up at shorter distances. All these piers were painted black with white lines from 2 to 6 inches wide, according to their distances, to denote the precise line with which the centre of the tunnel was to coincide throughout its whole length. A straight line from the centre of one of the distant marks to the centre of the other in the opposite direction should pass through the telescope when set for use so as to coincide with the line of collimation.

The transit being thus properly fixed, and a distant mark selected in the line of the tunnel, and a fixed spot placed at a considerable distance as a point of adjustment for the line of direction, the intermediate marks for the positions of the shafts may then be correctly set out; and when these shafts have been sunk, the points as determined by the transit instrument are carried down by means of iron plummets carefully suspended, and let down in buckets of water or cups of mercury to check vibration. A second transit instrument is then mounted at the bottom of each shaft in succession as far from the plumb-line as possible, and the intersection of the vertical wires in the transit with the plumb-line will evidently give the means for setting out the work correctly, and forming junctions between the several workings or *shifts*. In the Box tunnel, in a length between two shafts of 1,520 feet and with a slope of 1 in 100 the junction of the two shifts was perfect as to level and did not differ more than $1\frac{1}{4}$ inch in any place at the sides.

The working shafts are of course made sufficiently large to lower men and materials, for raising the earth or rock excavated, for fixing pumps, &c. These shafts are generally from 8 to 10 feet in internal diameter; they are lined with brick usually 9 inches thick.

and are curved 8 to 10 feet above the surface of the ground, and are finished with a stone coping. In sinking a shaft the earth is first excavated until it begins to appear too weak to stand by itself. A

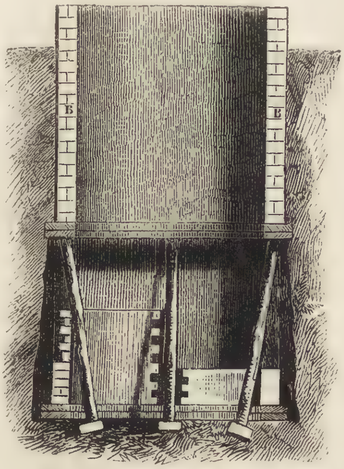


Fig. 2185. SINKING A SHAFT.

wooden curb or ring (shown in the section, Fig. 2185), as wide as the intended brick lining, is then placed at the bottom of the excavation, and on this the brick-work B B is laid. This part of the shaft is often not more than half a brick, or 4½ inches thick. When completed, the excavation is carried down even with the inner surface of the brick-work, so that the earth beneath the curb serves as a support, and diagonal props of timber (as shown in the figure) may be used if necessary. When the excavation has been carried down so far below the curb that the ground again appears weak, a second curb is inserted in a groove cut for the purpose, and the ground between the 2 curbs is divided into 4, 6, or 8 vertical masses, one or two of which are removed to a depth equal to the thickness of the brick-work. The wall is then built up in the spaces thus made for it; one or two other vertical portions are removed and built in, and so on until the lining is completed. By this method of *underpinning*, as it is called, the shaft is carried down to the full depth. The working shafts and the air shafts rest on curbs of cast-iron fitted into the crown of the tunnel, and forming level bases for them. But when the shaft has been sunk to the required depth, the brickwork must be supported in some way, before any excavation for the tunnel can be made below it. This support is made either by placing horizontal timbers below the brickwork, or by suspending the brickwork by means of iron rods, secured to timbers resting on the surface of the ground. The air shafts are similar to the working shafts, only of less diameter, 3 feet being generally sufficient. These are not sunk at a less distance that 50 yards from the working shafts. In some tunnels a large oblong opening, called an *eye*, is introduced, instead of ventilating shafts. In the Bishopton tunnel there is an eye 300 feet long. Horse-gins are usually employed in raising and lowering the materials, and in drawing water up the shafts, unless large pumps are employed with steam-power to work them.

The greater the number of working shafts the more men can be employed, and the quicker will the work be done. Some of the old canal tunnels occupied as many years in their construction as some of the modern railway tunnels have occupied months. Thus the Harecastle tunnel on the Trent and Mersey canal was 11 years in being formed under Brindley. It is 2,880 yards long, 12 feet wide and 9 feet high. It is lined with a semicircular brick arch, and was completed for the small sum of 3*l.* 10*s.* 8*d.* per yard. The new tunnel required by the increased traffic on the canal was commenced by Telford in 1822; it is 2,926 yards long, 14 feet wide, and 16 feet high, with an iron towing path, supported so as to allow the water to play freely beneath it. This tunnel, (a cross section of which is given under NAVIGATION INLAND, Fig. 1499, and the centering used in its construction in Fig. 1500,) notwithstanding its increased dimensions, was completed in less than 3 years. Many railway tunnels of superior magnitude have been completed in much less time, on account of the large number of working shafts. Thus the Watford tunnel, 75 chains long, was worked with 6 shafts of 8 feet diameter, and an air shaft was constructed at the distance of 50 yards on each side of each working shaft.

When the working shafts have been carried down to their full depth, narrow headings, or drift ways Fig. 2186, or D D, Figs. 2187, 2188, from 6 to 12 or 15 feet in length, 3 or 4 feet in width, and high enough for a man to work in, are excavated along the level of the upper or lower part of the tunnel, or such a drift may be formed throughout the whole length of the tunnel before any part is opened out to the full size. The kind of strata to be worked and the amount of drainage required are thus ascertained, and moreover the continuous heading serves as an adit or drain. Contracts for tunnelling are often not let until such a heading has been formed by the Company. The top of the heading should be so much above the intended soffit of the tunnel-arch as to admit the thickness of the brick-work besides the bars of timber and boarding by which the roof of the heading is supported, also allowing several inches for the settlement of the timber, which always occurs in excavations before the brick-work can be got in. Unless this allowance be made, the brick-work will be forced down, and can only be raised by removing the superincumbent earth piecemeal and at great cost. Bars *b b*, Figs. 2187, 2188, and polings *p p*, and pack-

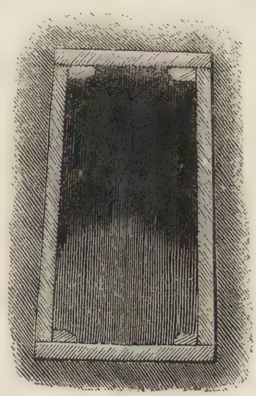


Fig. 2186.

ing boards are introduced as required. "The heading is extended on either side by cutting first narrow gaps horizontally, or rather dipping downwards in directions following the intended form of the tunnel-arch. Into these gaps crown bars are laid lengthwise and supported upon props; and poling boards are put in between them, to retain the earth at the sides of the excavation when extended. When the heading has thus been widened by excavating right and left, and a sufficient length cleared, the centerings are fixed and the brickwork is commenced. As this proceeds the

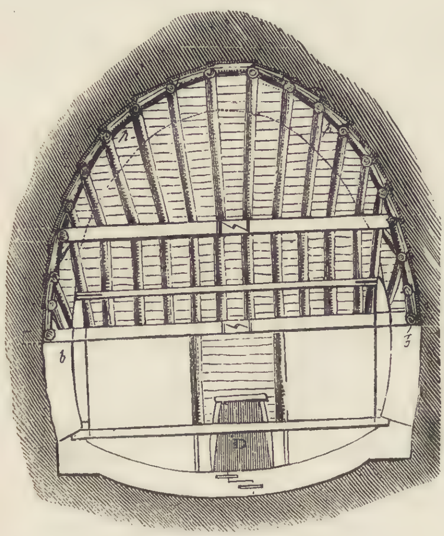


Fig. 2187. CROSS-SECTION OF TUNNEL.

Fig. 2188. LONGITUDINAL SECTION.

earth is carefully rammed behind it, and all vacancies filled up, to prevent any subsequent settlement of the surrounding earth upon it. The crown bars which were inserted in the heading and always during the excavations, are not always removed. If they can be drawn forward as the heading advances, without disturbing the adjacent ground, and the spaces filled up with broken stone, or other suitable material, no objection can arise; but otherwise they should be allowed to remain and be built in. The whole of the operations require careful regulation, so that none of them shall advance too rapidly for those which follow. The contractors are therefore usually restricted to carry the excavation not more than 6 or 8 feet in advance of the brick-work, or less, if so directed by the engineer, should any change occur in the strata which he thinks may require such precaution. When the faces of two contiguous excavations approach within about 50 yards of each other, a heading should be driven quite through the intervening ground, and the workings joined before the whole excavation and brick-work are proceeded with."[1]

The sides of the tunnel are curved or *battered*, the amount of curvature as well as the form of the arched roof depending greatly on the kind of ground to be supported. When, as in the case of the Primrose-hill tunnel already referred to, and shown in section, Fig. 2189, a shifting clay is to be supported, such a material will press nearly equally in every direction, and the tunnel will very properly be made to approach the circular form. The invert I, which is formed of 3 concentric half-brick rings, is a curve of 25 feet radius: the arch R R, of 4 half-brick rings, is struck with a radius

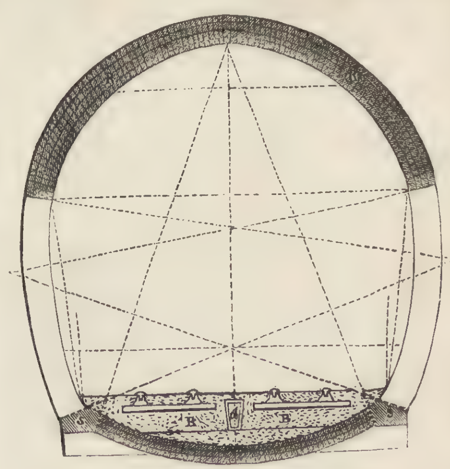


Fig. 2189. SECTION OF PRIMROSE-HILL TUNNEL.

of 11 feet 9 inches, the sides are arcs of 27 feet 6 inches radius. The brick lining, as already stated, had to be increased from 18 to 27 inches. The width of the tunnel is 21 feet 5 inches at the springing of the invert, and 24 feet 8 inches at the widest part. The clear height is 21 feet 8 inches, a depth of 3 feet 4 inches being occupied by the ballasting B B, drain *d*, &c.[2] The invert and the arch should be built in half-brick rings, and the proper number of bricks put into each ring, to ensure uniform bearing. Each ring should

(1) Dempsey's "Practical Railway Engineer." 4to. London, 1847.

(2) Further particulars respecting the design and construction of this and other tunnels will be found in "Railway Practice," by S. C. Brees, C.E. &c. 4to. London, 1837. A second series was published in 1840.

usually contain 5 more bricks than the ring immediately within it. The side walls may be built in English bond, or alternate courses of headers and stretchers. The best bricks should be used, and if the form of the tunnel require it the bricks should be moulded of a taper shape. Every brick should be bedded with a wooden mallet, and the joints if in mortar well flushed up. The brick drain should be built in Roman cement, with the joints left open for about half an inch to admit water from the ballasting. Water should be excluded as much as possible during the building of the tunnel and shafts, by puddling with clay. It will, however, often penetrate through the brick-work, an inconvenience which has been remedied by lining the roof with sheet zinc. The Thames tunnel has an interior lining of cement, with channels in the brick-work behind it for the passage of water. The ballasting for the roadway should not be such as will retain water; it should be well rammed down, and the blocks or sleepers be carefully bedded, and, as an additional security, it is usual to place the sleepers or points of support closer together in tunnels than on other parts of the line.

The following table presents some of the most important particulars respecting a few remarkable tunnels:—

Name.	Purpose to which applied.	Extreme height.	Extreme width.	Thickness of lining at crown of arch.	Length.	Nature of strata.	Material of lining.	Total cost.	Cost per yard.	Date of completion.	Name of engineer.
		ft. in.	ft. in.	ft. in.	yards.			£	£		
Thames and Medway..	Canal, and afterwards North Kent Railway	39 · 0	35 · 6	1 · 2	3,960	Chalk and fuller's earth	Brick-work	...	...	1800	W. T. Clarke.
Islington Tunnel	Regent's Canal	21 · 6	20 · 0	1 · 6	900	London clay formation.	ditto	...	...	1812	Morgan.
Harecastle Tunnel	Tetney Haven Canal..	16 · 2	17 · 0	1 · 2	2,962½	Various strata.	ditto	112,681	38½	1827	Telford.
Watford Tunnel.........	North Western Railway......................	26 · 6	27 · 0	1 · 6	1,830	Chalk.	ditto	...	...	1838	R. Stephenson.
Box Tunnel..............	Great Western Railway......................	36 · 0	36 · 0	2 · 3	3,123	Freestone.	ditto	...	...	1838	Brunel.
Littleborough Tunnel	Manchester and Leeds Railway	27 · 6	27 · 0	1 · 10½	2,860	Various strata.	ditto	251,000	88	1841	G. Stephenson.
Thames Tunnel	Foot Passengers.......	22 · 3	37 · 6	2 · 6	400	London clay.	ditto	454,714	1,137	1842	Brunel.
Blechingly Tunnel.....	South Eastern Rail-Railway................	30 · 0	30 · 0	1 · 10½	1,324	Shale.	ditto	95,237	71	1842	W. Cubitt.
Saltwood Tunnel........	Ditto.................	30 · 6	30 · 0	2 · 3	954	Lower green sand.	ditto	112,542	118	1843	ditto.

The Thames Tunnel is well known, and has been often described in a popular manner; but as an article on tunnels would not be considered complete without some account of it, we will notice very briefly its history and construction.[1] It was proposed as early as the year 1798, by Ralph Dodd, the engineer, to open a passage under the Thames, at Gravesend, so as to connect it with the Essex shore. In 1804, Chapman proposed a tunnel at Rotherhithe, and in 1807 a commencement was made, by sinking a shaft at a distance of 315 feet from the river; but the constant influx of sand and water defeated the project. Trevithick was then engaged to drive a way under the bed of the river, and he succeeded in forming a drift 5 feet in height, 2 feet 6 inches in breadth at the top, and 3 feet at the bottom, for a distance of 1,046 feet under the river; but the water broke in upon the workmen, and the project was abandoned until, in 1823, a Company was formed to carry into effect the plans submitted by Mr. afterwards Sir Mark Isambard Brunel, which may be briefly stated as follows:—A shaft, 50 feet in external diameter, the walls being 3 feet in thickness, was sunk by first driving 24 piles, with a shoulder projecting, on the side of each, within the circle intended to receive it: on these was laid the timber curb, which also partly rested on one of cast-iron, the latter having a sharp cutting edge, which entered the ground; through this curb were passed 48 wrought-iron bolts, 2 inches in diameter, to a height of 45 feet, equal to the top of the intended shaft. On this curb the shaft was built with bricks laid in cement, and as the work proceeded, it was bound together by 26 circular timber hoops ½ inch thick. When the brickwork was completed, another timber curb was placed on the top, and through this the long iron bolts were passed, and their ends being formed into screws, nuts were put on and screwed up, so as to make the shaft as it were one mass. When the cement was sufficiently hard, the earth within the shaft was excavated; 16 of the piles on which the shaft rested were driven in pairs opposite each other, half an inch at a time, and then the whole gradually sunk, carrying with it the other 8 piles. The 16 piles were next drawn out by opening the ground at the back, when the whole weight of the brick shaft, =910 tons, then rested on the 8 piles, and these were afterwards drawn when a bed of gravel had been reached. The shaft was thus passed through a bed of wet sand and gravel, 26 feet deep. At the depth of 40 feet, the shaft became earth bound, and it was necessary to complete it by *underpinning* the brickwork, *i.e.* building it downwards as the excavation was carried down. The loose nature of the

(1) There is a very good popular account of the Thames Tunnel in Knight's London, vol. iii. The fullest, and in every respect the best account, is a memoir by Mr. Law, in Weale's "Quarterly Papers on Engineering." An abstract of this memoir is given in Weale's "London in 1851;" and also in Mr. Law's "Rudiments of Civil Engineering," contained in Weale's Rudimentary Series.

ground rendered this a matter of difficulty. This lower portion of the wall was increased in thickness to 4 feet, and was built of rag-stone, laid in mortar composed of cement and lime, and lined with 2 courses of brick laid in cement. At the depth of 80 feet an invert was formed, and in the centre a smaller shaft, 25 feet in diameter, was sunk still deeper, to serve as a well for water from the drains of the tunnel; but at the depth of about 80 feet from the surface, the ground suddenly gave way, and a quantity of sand and water was blown up. The excavation for the tunnel was 38 feet wide, and 22 feet 6 inches high, and in order to leave a sufficient depth of ground in the middle of the river above the brickwork, the tunnel was formed with a declivity of 2 feet 3 inches in 100 feet. The ground above was supported while the excavation was going on by a *shield*, consisting of 12 massive iron frames, placed side by side, and capable of being slid forward, independently of each other, for a short distance, by means of screws abutting against the end of the completed brickwork, which followed closely on the excavation. The shield was supported on flat soles, capable of being easily moved forward; the top and sides were also closed in by flat plates, which were supported by massive framing, and also fitted close to the brickwork, by which means the soft earth was prevented from falling in. Each frame of the shield consisted of 3 stories, with a cell in each, in which one man could work; the front of each cell was protected by a series of narrow poling boards, each of which was held in its place by an arrangement which allowed it to be fixed in a vertical line even with the face of the shield, or a few inches in advance thereof. Each miner began operations by removing the upper poling board in his division of the shield, and excavating the small portion of earth thus exposed to the depth of about 6 inches; he then replaced the poling-board, and caused it to press, by means of jack-screws, against the face of the excavation; he next removed a second board, whereby a fresh portion of earth was exposed and excavated as before. When all the poling boards in one frame of the shield had thus been advanced 6 inches, the frame itself was moved forward, and the same series of operations repeated. The frames of the shield were thus alternately moved forward, slowly and with great caution, the brickwork following close upon the shield, and enclosing two arched passages, 26 feet 4 inches in height from the invert to the crown of the arch, and 13 feet 9 inches span at the springing of the arch. This shield was so damaged in the course of the work that it had to be taken down, and a new one raised. The new shield will be described at the end of this article. The arch, the invert and the curved side walls are laid in concentric rings, either a whole brick or a half brick in thickness, each ring presenting a plain face, no bond being employed between the successive rings. The tunnel is built with the hardest picked stock bricks; the first or inner ring of the arch is laid in pure cement, and the other portions of the work in half cement, and half clean sharp sand. The bricks for the semi-circular portion of the arch were moulded to the true wedge form, so that the bricks radiated with parallel joints between them. The total thickness of the brickwork at the thinnest points where the enclosed arches approach nearest to the boundary of the rectangular mass of brickwork, is 3 feet. A solid wall, 3 feet 6 inches thick at the top, and 4 feet at the bottom, was constructed between the arches; small transverse arches being afterwards cut through it at intervals to form openings from one tunnel to the other. The whole of the brickwork is laid in Roman cement, and each archway is to be finished with a lining of cement, a carriage-road, and a narrow footpath adjoining the central wall. Only one archway, however, has been thus completed. A brick drain is laid down from the centre or lowest point of the tunnel, to the Rotherhithe shaft, by means of which any water that percolates through may be removed. The inclination of the roadway conducts the water from the other half of the tunnel into the drain.

The excavation of the tunnel was commenced in January, 1826, in a stratum of clay; but in a few weeks much difficulty was experienced, in consequence of meeting with a break, or fault, filled with sand and gravel. This obstacle, however, was passed through in 32 days, and by the end of the first year, 350 feet of the tunnel were completed. Moist clay was occasionally forced through the shield. Cavities in the bed of the river had to be frequently filled with bags of clay, to prevent the water from breaking through. In examining the bed of the river, in a diving bell, a shovel and a hammer were left in the river, and these were afterwards found in a mass of loose earth which broke into the tunnel. The works were continued until the 12th May, 1827, when the river broke in with such rapidity and violence, that Mr. Beamish, the engineer on duty, and the men under him, narrowly escaped being overwhelmed. On examining the bed of the river in a diving bell, it was found that about 25,000 cubic feet of earth had been displaced. Tarpaulings were put down over the hole, and filled up with bags of clay and gravel. The tunnel was then pumped dry, and was entered on the 27th June, when the finished part was found to be uninjured. It was not until the end of September that the shield was again advanced; but the progress was very slow; the influx of water was very copious, and on one occasion it amounted, for several hours, to 1,200 gallons per minute. By the middle of January, 1828, another 50 feet had been added to the tunnel, making the length of the finished portion 605 feet; when on the 12th the river burst in so suddenly, and the tunnel filled so rapidly, that of seven persons in the works, Mr. Brunel alone escaped; he was hurried along by the flood, and was carried up the shaft by the rush of water. The hole in the bed of the river was filled up, and on the 12th of April the shield was again entered. By this time, however, the funds of the company were nearly exhausted, and the works were suspended. In order to render the tunnel as secure as possible during the suspension of

the works, a solid wall was built at the unfinished end of the arches, so as completely to shut out the river. One arch of the finished portion was lighted with gas, and opened to the public; and it proved, for a time, a very attractive exhibition. After repeated applications, Government consented to advance money for the completion of the tunnel. A new shield was substituted for the one which was injured by the irruption, and from that time, until 1842, the work slowly progressed at the rate of a few inches per week. Three more irruptions had taken place, in one of which a miner lost his life; the same remedy was applied as before, and the bed of the river over the shield was constantly watched, soundings taken at every tide, and bags of clay and gravel thrown in when any depression was discovered. As the tunnel approached the Wapping shore, a shaft was commenced on that side of the river, and the further progress of the tunnel stopped until the shaft was completed, as it was supposed that some settlement in the tunnel might be produced during the sinking of the shaft if brought too close to each other. The shaft was made 55 feet in external diameter at the bottom, and 53 at the top, this taper form being given to prevent its becoming earthbound. On the 13th August, 1841, Sir M. I. Brunel passed from this shaft into the tunnel along a small driftway. By the latter end of November, the middle frames of the shield had touched the brickwork of the shaft, through which it was passed in the same manner as it had passed through the ground. The brickwork of the tunnel was made good to that of the shaft, and on Lady Day, 1843, the tunnel was opened for foot passengers. The approaches for carriages, which are proposed to be by spiral roads, formed round the sides of shafts, or circular excavations, 200 feet in diameter, have not been constructed. The tunnel is 1,200 feet long between the two shafts. The total cost of the tunnel, up to the present time, is 454,714*l.*, of which 180,000*l.* was subscribed by the original shareholders, or was raised upon debentures, and the remainder was advanced by the Exchequer Loan Commissioners. To complete the carriage descents, or approaches, would require a further sum of 180,000*l.*, thus making the total cost of the tunnel 634,714*l.*, or about half the cost of Waterloo or London Bridge. The toll is one penny for each person, and the yearly receipts from this source, and from rents (the cross arches being fitted up with stalls for the sale of toys, &c.), do not amount to 5,000*l.*, a sum scarcely sufficient to cover the necessary expenditure, in consequence of the constant influx of land springs.

We will conclude this article with a description of the new shield above referred to.

The junction of the shield was to keep a *temporary lining* of planks or iron plates pressed out in all directions against the whole unfinished part of the excavation, until this lining could be replaced by the advance of the permanent one of brickwork. The brickwork was always completed up to about 9 feet from the extreme end or face that was being excavated, so that the surface to be lined in this temporary manner consisted of 5 planes, the front or end plane, containing about 850 square feet, the two sides, for a length of 9 feet, containing about 220 feet each, and an equal length of the roof and floor of the excavation containing about 350 each. The front plane, of course, was composed of numerous small pieces or *polings*, so supported that each might be removed singly without disturbing its neighbours, and replaced and pressed further forward after the removal of a small thickness of the ground before it. A single poling measured only about 37 inches by 6, placed horizontally, so that there were 12 in the width of the work, and 44 in its height, or 528 in all; and each was only kept open at one time long enough to excavate its own thickness, which was 3 inches. Now the problem to be accomplished was, without interfering with this capability of being singly removed, to afford them all equable support or resistance, as well as to every part of the other four lining planes, above, below, or on each side,—that is, to receive separately the inward pressure of every small piece thereof, and transmit it all to the solid face of the brickwork behind, (this face being interrupted by two oval voids of 17 feet by 14, forming the double tunnel,) and this without blocking up the space in which the miners had to work; and further, in such a way that the pieces finally abutting against the brickwork might have the pressure alternately transferred from some of them to others, to leave every part of that brick face successively free to be built forward; and lastly, so that the whole mass of this machinery might be progressively advanced, as the excavation proceeded in front, and fresh additions were made to the masonry behind.

The whole movable structure thus occupying a space 37 feet 6 inches long or broad, across the tunnel, 9 feet thick or deep in the direction of its length, and 22 feet 3 inches high, was exclusively of iron, chiefly cast, and forming 12 independent portions called *frames*, placed side by side like volumes in a library, in order that six alternate ones (numbered 1, 3, 5, &c.) might be released from pressure, and shifted forward, while the other six were transmitting the whole pressure to the brickwork behind, from all the polings, both before themselves and before their neighbours, which in their turn furnished all the resistance when these other six were being advanced. Both the abutment or horizontal support from the brickwork, and means of pushing forward each frame, were afforded by large screw-jacks, two for each frame, seen at *f f*, Fig. 2191, applying themselves by ball and socket-heads, and broad hands *h h* against the brickwork, one above and the other below the mouths of the archways. Of course these, which were called the top and bottom *abutment-screws*, could be at any time removed from those six frames that were not supporting polings, and thus the brickwork was continued forward by successive vertical slices or courses, either of a brick's thickness 3 inches, a brick's width, 4½ inches, or a brick's length, 9 inches; but most com-

monly of this last extent, as shown in the figure. There is no more connexion or bond between these courses or additions than between the horizontal ones composing an ordinary building; and the two arches in each were turned upon the same two narrow bits of centering (one seen at *v v*), which were carried through the whole work, being lowered for an advance by the apparatus *w x y*, resting on a stage thrown across at the level of their springing, on the stone salient courses B B.

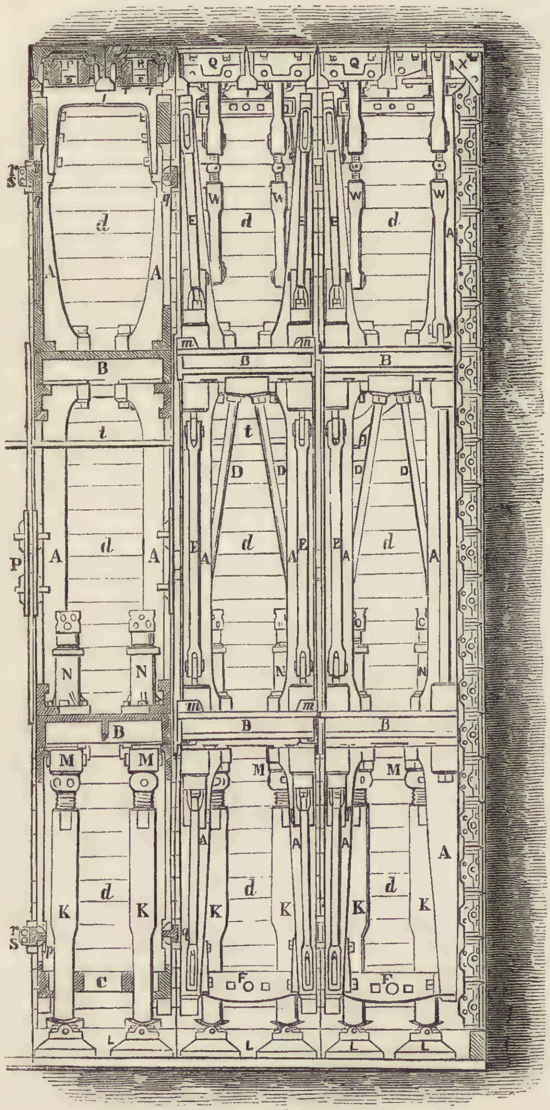


Fig. 2190. ELEVATION OF THE 3 LEFT-HAND FRAMES OF THE SHIELD.

The absence of any longitudinal bond is a great disadvantage, rendering the whole like a tube made up of thin flat rings, only cemented together. This mode of building also rendered it necessary to carry on the wall between the tunnels quite solid, and afterwards *cut out* the cross archways that seemed necessary for convenience, and to moderate the oppressive effect of so long a passage unvaried.

Of the 12 frames thus independently spanning the tunnel's end from top to bottom, each might be considered a kind of vertical bridge, or pair of parallel beams or joists, for if the reader turn the figure round with the polings *d d* upwards, the whole resembles a deep perforated iron beam or bridge, resting by its ends on the two pillars *f f*, and bearing by the numerous little pillars *e e e*, &c., the ends of the poling-boards *d d d*, which span across from one side of the frame to the other, as the planks of a foot bridge do from one to the other of its two beams or bearers. Now as beams or bridge bearers of this kind, in iron, are often made in three lengths, and the two end pieces sloped off to a less depth than the middle piece, so here the frame will be seen to consist of three parts in height, firmly bolted together, and the upper and lower ones sloped off to save material. They were called *boxes*, being in fact skeletons of boxes, or boxes open on every side except a wide margin A A A, &c., and in putting them together, two *floor-plates* of iron, B B, were interposed between the lower and middle and the middle and upper box, so as to make each a convenient working-place for one miner. The whole shield therefore admitted 36, in three tiers or stories, and each had commonly only one of the polings before his box removed at a time, as shown in the middle box, Fig. 2191, though in good ground two were allowed to be taken at once, as shown in the lower box. In case of an uncontrollable "run" or irruption of quicksand into any box, that box had its sides and entrance barricaded with boards, and the influx effectually confined to it, until the compression of the matter intruded made it manageably firm, so that it could be removed, and the box again taken possession off; and in this way, several "runs" that would otherwise have been quite ruinous, were mastered with a few hours' delay only. Clay would often intrude itself illimitably through apertures hardly perceptible, or not admitting a finger.

Before proceeding to the modes of supporting and managing the polings, we must notice the singular mechanism for moderating the friction, which, in pushing any frame forward simply by the two great screws *f f*, would have arisen from its contact all round, both against the roof and floor of the excavation, and against its neighbours, all being strongly bound together by the tendency of the earth to collapse upon them in every direction. The friction against the roof and floor (which might, it seems to us, have been very simply obviated by a mounting on broad-tired wheels,) was met by a very complex and unique contrivance, compared to a man's arms, legs, knee-joints, ankle-joints, feet and shoes; and apparently planned only to exhibit this fanciful resemblance, for the mode of progression with these members was so entirely different from walking, that

much seems to have been sacrificed to (rather than gained by) this unreal imitation. Though each frame had two legs, K K in the above figure, and K K K, &c., in Fig. 2191, the two were not lifted or advanced alternately, but both at once, as in using crutches, so that *one* central foot would have answered every purpose of the two. During their relief from pressure by shortening them, for each was a great screw-jack, and turned by levers inserted into M, the frame was upheld by its *arms,* (also called *slings,*) one of which appears at O O, Fig. 2191, which either hung from, or bore upon the neighbour frames on each side. These arms, 11 in number, connecting each frame with the next, might be lengthened or shortened to a certain extent by wedges placed in them at P. When *lengthened,* they acted as pillars to lift up those frames to which their heads were connected, and throw all the weight on the six other frames which their lower ends bore upon; but when *shortened,* they acted as slings or suspenders, to draw up these latter frames, and hang their weight to the intermediate ones, which before were lifted, but now bore on their legs and feet. Thus, by these two actions, it was easy alternately to relieve the legs of all the six even-numbered, or all the six odd-numbered frames from pressure, and consequently from friction against the floor; and the travelling of the whole shield resembled that of a rank of twelve men not walking, but each of whom advances both feet at once, by hanging with his arms on his two neighbours as crutches, and then in his turn stands

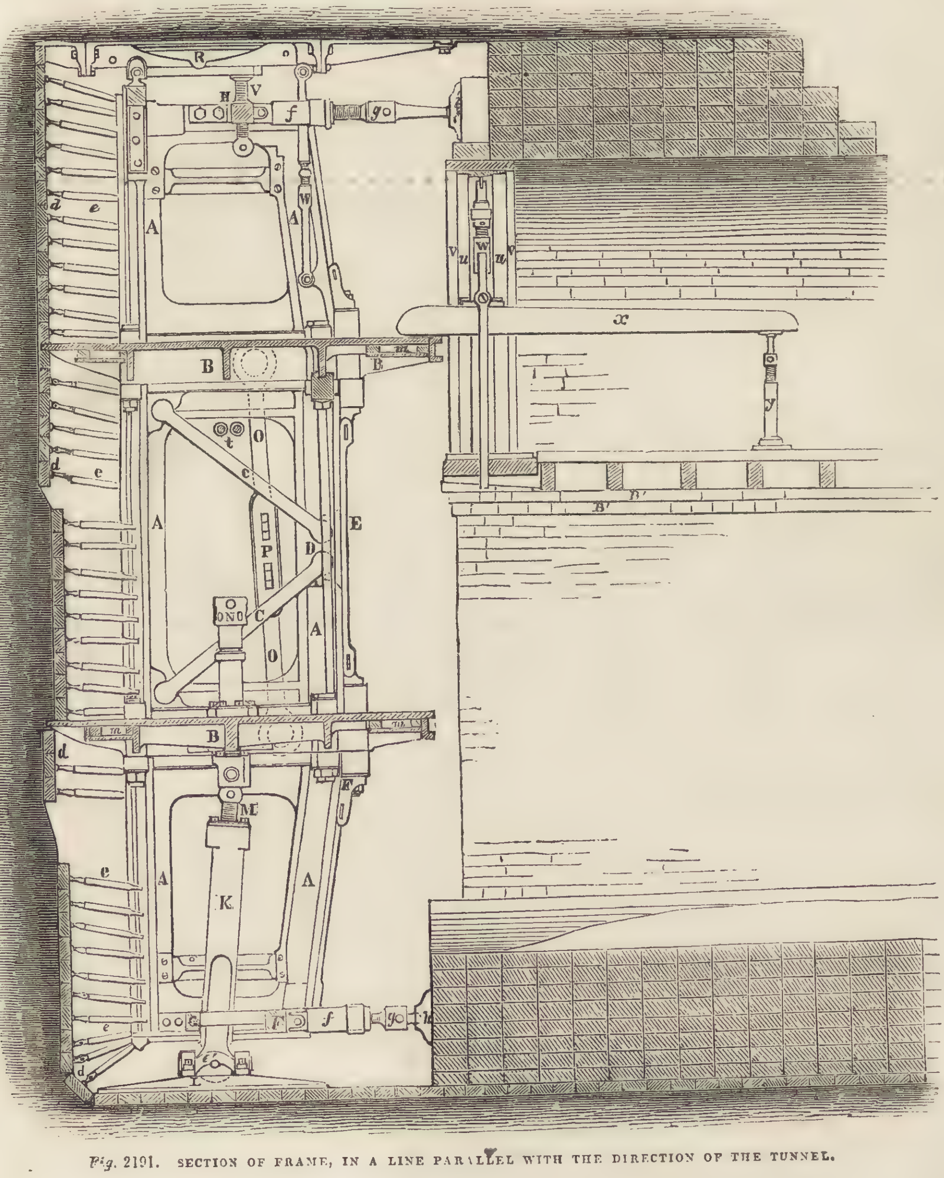


Fig. 2191. SECTION OF FRAME, IN A LINE PARALLEL WITH THE DIRECTION OF THE TUNNEL.

still to serve as a crutch for them in their advance. Each move of every frame was exactly 6 inches, viz. from 3 inches behind its neighbour frames to 3 inches in advance of them; and the whole shield never stood in one even rank, but six alternate frames always 3 inches behind or ahead of the others; and this distance was, in the second shield, accurately maintained by a kind of stops to their motions, inserted between the upper and between the lower boxes at *q r s*, Fig. 2190, and called the *regulators*.

There was nothing in the original shield (used up to the second irruption, and exhaustion of the Company's funds in 1828,) to obviate the friction of one frame against another, except small rollers and wedges introduced at discretion. The consequence was, that they often got into actual contact, and the enormous sliding friction to be overcome when they were thus jammed, led to continual fractures of themselves, their legs, arms, and abutment screws. Fig. 2192 shows the means by which they were kept apart at one constant distance of about 3 inches, in the improved shield. It is the underside of the front ends of three contiguous floor-plates, and there was a similar appendage to their hinder ends. The two sectors *l l*, (called *quadrants*,) turned on centres in the even-numbered frames, and entered into two recesses *m m*, Figs. 2190, 2191, attached to each odd-numbered one. Every frame was steadied in its advance between 8 of these sectors, two acting before and two behind, upon each of its two floor-plates. We speak of course of the 10 frames from No. 2 to 11 inclusive, for the two extreme ones necessarily differed in many respects from the rest, which were all alike.

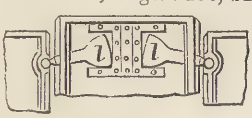


Fig. 2192.

The mode of working can now be understood from the three figures I, II, III, Fig. 2193, exhibiting three positions of the fronts of three contiguous frames and the polings before them. Each poling was supported against the earth by two small screw-jacks, applied to hollows in its face, lined with iron near its ends, and abutting by their tails against the upright sides of the frames. This being the condition seen at I, and the 6 odd-numbered frames being 3 inches behind the others, the miner in the middle box of the figure (being an odd-numbered one), loosened the two screws supporting the uppermost poling before that box, removed the poling, and 3 inches of the ground before it, and replaced it in one plane with those on each side of him, as seen at II, only resting its screws now not against his own frame, but against its neighbours on each side, as shown in the figure. He next loosened the second of his polings, and when all had successively been worked forward, as the same process was going on in all the 18 cells of the 6 odd-numbered frames, the whole of the polings were brought into one plane. In Fig. 2191, we have shown this process completed in the top box, 6 polings replaced, and the 7th open in the middle box, and 3 replaced and 2 open at once in the lower box. When all were worked forward, it is plain that they would abut solely on the 6 even-numbered frames, leaving the others free to be advanced from A to B, Fig, 2193, which was done by throwing their weight on their neighbours by the arms or slings O, Fig. 2191; then placing the shoes L, which were thus left free, 6 inches further forward, which brought the legs into the sloping position there shown, then screwing on the whole frame that distance by its 2 abutment screws, *f f*, and, lastly, by relieving the slings, resting it on its own feet again in a position 3 inches before, instead of 3 inches behind its neighbours, as outlined at B, Fig. 2193. The same polings were now removed again in the same order as before, and another 3 inches excavated, and the poling screws replaced against their *own* frame, as at III, Fig. 2193, which, it will be observed, is in the same condition as I, except that the odd tiers of polings are in advance of the even ones. The same processes were now repeated, therefore, to advance the even-numbered frames, and the whole brought into its precise original condition, when every part is 6 inches further forward. Most of this immense work was excavated by the bare hands, without tools.

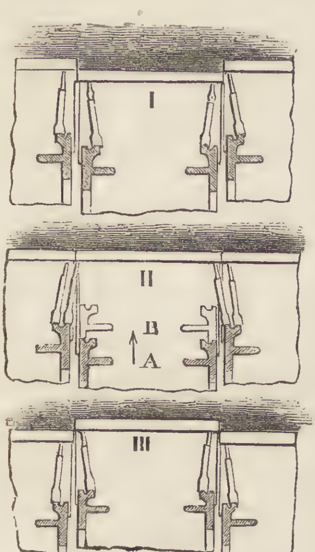


Fig. 2193.

The protection of the top and sides, as well as of the front, was in numerous, narrow, horizontal pieces, which were called *staves*, and being pushed forward as the work advanced, were of iron, and elaborately contrived with a view to serve throughout the undertaking. In Fig. 2191, both the top and side ones are seen cut transversely, and in Fig. 2190 a top stave cut longitudinally at Q Q. These were made to slide with as little friction as possible on supports R, called *saddles*, and were each separately adjustible by the screw-jacks *v w*, so as to press them up with more or less force, and preserve the different inclinations necessary in the curved descent and ascent given to the tunnel. Each stave, whether of the top or sides, was in 4 lengths, as seen in Fig. 2191, 3 of cast-iron and 1 of wrought, the foremost entering like a chisel into the ground, 6 inches before the face of the polings, and the hindermost, called the *tail*, being a thin plate overlapping the brickwork some inches; so that the staves covered the edges, both of the front plane and of the new face of brickwork, as those of a cask do the edges of both its heads. It is one of the remarkable instances of the hurry and thought-

lessness which characterise many great English engineering works, that even so simple and obvious a piece of design as this, had to be evolved by the most ruinous experience. The staves of the original shield had actually neither cutting points nor tails, that is, the meeting of the lateral and top protections with the front one was left to be made good by random expedients, and opened entirely at every move of the polings; and the whole, instead of enclosing and embracing the end of the brickwork, like the cover of a telescope or band-box, was simply placed before it, with sufficient interval generally to allow for the building it forward. It is equally inconceivable how, with all these precautions against the softness and pressure of the ground in every other direction, that from below could be so *utterly* ignored as to omit, at first, not only all protection of the floor of the excavation similar to that applied against every other part, but even all means of spreading the pressure of the frames over it, beyond the shoes that were of necessity placed under the very questionable contrivance of legs, or rather stilts. Still more remarkable is it that even when the necessity of planking under the brickwork presented itself, soon after the commencement, this planking was not extended under the shield, but each plank was laid down *behind* instead of before its feet, which, of course, sunk into the clay, or adhered to it immoveably, and the effects were augmented, and continual fractures of the legs produced, by their being, in the first shield, rigidly connected with the feet, instead of with an universal joint or ankle. At length the planks were laid before them, close up to the lower polings, and recognised as part of the general lining that left no earth bare, except the points at any time being excavated. This floor is of elm, 3 inches thick, like the temporary protections.

In the general form of the shield, and, consequently, of the whole work performed with it, the rectangular section of the whole prism excavated and filled with brick, it is difficult to overlook the great waste of human labour and life, caused by men and companies, who undertake such works on the supposition that the *whole* of the thought about them can be delegated to others. It can hardly be questioned that the flat top and vertical sides render this shape nearly, or quite the worst for its permanent functions as a tunnel through settling and yielding clay; and the fact of every one of the five irruptions occurring at an upper *corner* of the prism forcibly suggests the question whether, had there been no upper corners, there would have been any irruption. Moreover, every irruption was into a space (the outer spandrils) that it was not only totally needless to excavate and useless to fill, but which had actually better, for the permanent uses of the work, have been occupied by the natural ground than by the masonry now filling it. On looking at the well-known cross section of the tunnel, it would seem that no portion of the *non-radiated* brickwork, except that between the heads of the tunnels (which ought to have had about half its material saved by a cylindrical perforation) adds anything whatever to the strength of the work; while it certainly made the liability to dislocations of the ground, above the rectangular corners, a maximum. Here is about one-eighth of the whole bulk, then, excavated, only to be filled up again with, at least, a third of the whole masonry, or several million bricks, for no apparent reason but that the shield might be rectangular, that is, might admit of all its 12 portions being alike, or made to *one design*, instead of the *six designs* that would have been necessary had they diminished in height from the centre to the sides to suit an oval, or other better and more economical cross section.

TURBETH MINERAL, a term applied to the basic sulphate of mercury, $3HgO,SO_3$, from a similarity in its medical effects to those of the root *Convolvulus Turpethum*, which is violently cathartic and emetic. See MERCURY.

TURF. See FUEL.

TURKEY-RED. See CALICO-PRINTING—DYEING.

TURMERIC, the root of the *Curcuma longa*, a native of the East Indies, and cultivated about Calcutta, in Bengal and China. It is one of the constituents of curry powder and curry paste, and it is also used as a condiment, and as a colouring matter. The roots, or rather tubers of turmeric, are known in commerce as *round* and *long*. The round tubers are about 2 inches long, and an inch in diameter, pointed at one end, and wrinkled. Long turmeric is cylindrical, about ½ an inch thick, 2 or 3 inches long, and somewhat contorted. Both varieties are greyish-yellow externally, and internally of an orange-yellow passing into brown. The fractured surface appears waxy; the odour is aromatic and peculiar, the taste aromatic, and the tuber when chewed tinges the saliva yellow. The colouring matter of turmeric, *curcumine*, has been isolated; it is an inodorous, transparent, reddish substance, not crystalline, and it acquires a fine yellow colour when rubbed to powder. It fuses at 105°, and is scarcely soluble even in hot water, but readily so in alcohol and ether, and in fat and volatile oils, so that it resembles the resins in character. Curcumine forms red solutions with sulphuric, hydrochloric, and phosphoric acids, and on the addition of water, a pale green flocculent precipitate is produced. It forms reddish brown solutions with the alkalies, and hence the use of turmeric paper as a test. For this purpose, it is best prepared with a strong tincture of turmeric in proof spirit.

TURNING is the art of shaping wood, metal, or other hard substances into round or oval figures, by means of a machine called the *lathe*.

This art is of very ancient date. The potter's wheel, which is a lathe with a vertical instead of a horizontal axis, is mentioned in the Old Testament. Several of the ancient writers refer to the art. Pliny names Theodore of Samos as being the inventor of the art, and refers to one Thericles, who was famous for his skill at the lathe. It was a common expression among the ancients, that anything done accurately and delicately must have been formed in the lathe.

It is scarcely possible to over-estimate the import-

ance of this art. The various engines and machines employed in converting the numerous raw productions of the earth into useful fabrics and articles of comfort, convenience, or necessity, could scarcely exist in the absence of the lathe, and of the tools required for the accurate production of the circular parts which enter so largely, and so importantly, into their structure. Without the lathe, the production of the steam-engine would scarcely be possible, so much does the circle abound in its various parts. The same remark applies to the steam-printing machine, and to a large number of the most important instruments of science. Indeed, it is not too much to assert, that nearly all solid objects, especially of wood and metal, in which the circle or any of its modifications can be discovered, are the offspring of the lathe.

In the operation of turning, the work to be reduced to shape is put into the lathe, and made to revolve with a circular motion about a fixed line or axis: the external surface is then worked to the intended form by means of edge-tools presented to it and held fast down upon a fixed rest. The projecting parts of the work, by its rotatory motion, are brought up against the cutting-edge, and are cut off, and thus the outer surface is so reduced as to be at an equal distance from the axis of motion, and, consequently, it has a circular figure. In general, the axis, or centre line of the work, coincides with the centre of any sections made by planes perpendicular to such axis. A piece of work may, however, have 2 or more centre lines in different parts, or in different directions; but in such case the work must be turned at 2 or more successive operations. Or the position of the axis may be rendered movable during the revolution of the work, as in *oval* and *rose-engine* turning. The work may also be turned hollow, with a cavity inside; or the exterior surface may be fluted, or grooved, or variously shaped, or the work may be turned both inside and out.

The essential properties of the lathe for outside work are two *points*, which will firmly sustain the work at each end, and still allow it to turn freely round upon its axis; secondly, a *rest* or support for the tool; and thirdly, some contrivance for turning the work round. For hollow, or inside work, the work cannot, of course, be supported at both ends: it is therefore fixed securely to the extremity of a *spindle* or *mandrel*, which, on being turned round, carries the work with it, and the tool, being applied to the free end of the work, produces a hollow or excavation.

There are many forms of lathe. Where the work is supported at both ends it is called the *centre lathe*, and when fixed at the projecting end of a spindle, it is called a *spindle, mandrel*, or *chuck lathe*. Lathes are also named from the different methods of putting them in motion, such as the *pole lathe*, the *hand-wheel lathe*, the *foot-wheel lathe*. For very powerful works, lathes are turned by horse-power, water, or steam. The lathe is then called a *power lathe*.

The lathes used by the turners in wood are generally made of wood, and of simple construction; they are called *bed-lathes:* the lathes used for turning iron and steel are of similar construction, but different material; but the best work in metal is done in an iron lathe, which, when made with a triangular bar, is termed a *bar-lathe*. The small lathes used by watchmakers, called *turn-benches* and *turns*, are similar to centre-lathes, only smaller, and made of metal.

The centre-lathe, Fig. 2193, which is the most simple, consists of 2 beams of wood fixed horizontally on legs like a bench, forming the *bed* of the lathe. The beams are fixed a small distance asunder, the space between them being for the reception of the tenons at the lower end of the *puppets*, or short posts, which rise perpendicularly from the bed, and are firmly fixed

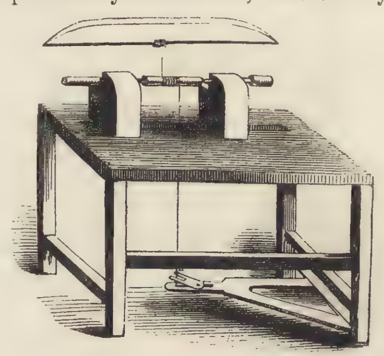


Fig. 2194. POLE-LATHE.

thereto by means of cross wedges passed through the tenons beneath the bed. One of the puppets carries an iron pin, and the other tenon has, at the same level, a centre screw working through a nut. Both the screw and the pin are furnished with sharp steel points, which pass into the ends of the work, and hold it securely. The rest, for the support of the tool, is a rail, or bar, extending from one puppet to the other, and lying in hooks projecting from the puppets. The work is put in motion by means of a treadle worked by the foot. A string or cat-gut is fastened to the treadle, and, passing 2 or 3 times round the work, is attached to the end of an elastic *pole* or *lath*, (whence the origin of the term *lathe* or *pole lath*,) fixed to the ceiling over the head of the turner.

In using this lathe the workman moves the treadle with one foot, and placing a gouge or chisel on the rest, he brings the edge carefully up to the work; the pressure of the treadle causes the work to turn round against the edge, which cuts it to a circular form. When the treadle touches the ground the man takes off his foot, and the elasticity of the pole draws up the treadle and turns the work back again: during this backward motion the tool cannot cut, and is removed from the work, but is again applied when he begins to press down the treadle. The desired effect on the wood must be produced gradually so as not to leave ridges; and knots in the wood must be acted on gently, or the wood may be split or the edge of the tool turned. For light work, a bow is hung over the centre of the lathe, as in Fig. 2194, and the string from the treadle is tied to the middle of the bow-string, which acts instead of the pole. The centre-

lathe is an imperfect machine when worked as above described, but its great simplicity causes it still to be used for turning the legs of stools, chairs, tables, staircase-rails, &c., in soft wood. It is also used in Spitalfields by the bobbin-turners, who work in alder, &c. In centre-lathes, the work is sometimes put in motion by a large heavy wheel turned by one or two labourers. An endless-cord passes round a groove in the circumference of the wheel, and after crossing, like a figure of 8, goes over a small pulley attached to the work. By this means the work receives a rapid motion, and has the advantage of turning in the same direction, so that the action of the tool is continuous. The centre-lathe will turn any kind of work that can be supported at both ends. For turning heavy work, such as millwrights' and iron-founders', the puppets are secured to the bed by means of nuts and screws instead of wedges, and to put the work in motion, the centre-pin of one puppet projects considerably, and a pulley is attached to it, so as to turn freely round by means of an endless-band or strap, which communicates motion from a great wheel, moved by water or steam-power. From the pulley, a pin projects in a direction parallel to the centre-pin, and a piece of iron, called a *driver*, is secured to the end of the piece of work so as to project from it sufficiently to be intercepted by the pin which is fastened to the pulley, by which means the motion of the pulley is communicated to the work.

The *spindle* or *mandrel-lathe*, Fig. 2195, is arranged for turning hollow work, and also centre work, as in the centre-lathe. Motion is given to the work by means of the foot, so that the turner has both hands at liberty. A A are uprights of oak or mahogany, which support the bed B, consisting of two bars of iron, with a space between them. Lathes entirely of metal are subject to an elastic tremor, which is unpleasant and injurious. C D is a cast-iron frame fastened to B for supporting the spindle or mandrel *a b:* E is the back puppet, used to support one end of the work G, the other end being fixed to the extremity of the mandrel, and turned round by it. E has a cylindrical pin fitting it, and the end of the pin has a conical point or *back centre*, which penetrates and supports the work, and the back centre can be moved forward by means of the screw *e*, while a clamp screw E binds the pin when adjusted. The back puppet is secured to the bed B by a tenon, which enters the groove through the bed, and a screw descends from the tenon quite through the bed and projects beneath it: upon this screw a nut *g* is tapped, and by turning it, the shoulder of the puppet E is drawn down firmly to the bed; and when the nut is loosened the puppet can be slid along the bed, and adjusted at any required distance from the extremity of the spindle, according to the length of the work G. The point of the back centre must be exactly in the centre line of the axis of the motion of the spindle *a b;* for which purpose the upper surface of the bed must be straight and flat, and the groove straight and parallel; the frame of the mandrel must be so fixed to the bed that the centre line of the mandrel is exactly parallel to the bed and to the groove. The neck of the mandrel requires to be accurately fitted into the collar, so as to turn smoothly without shaking. The neck at one end projects beyond the collar, and the projecting part is formed

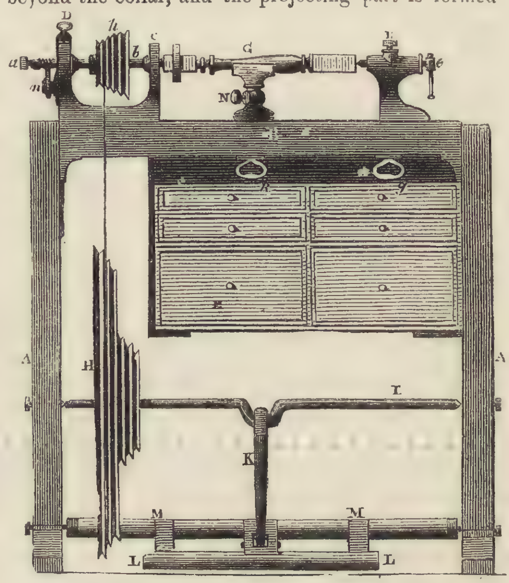


Fig. 2195. SPINDLE OR MANDREL LATHE.

to a screw for fixing the work to it. Upon this screw various pieces called *chucks* are fixed, each chuck being adapted to hold a different piece of work. The chucks screw up against a shoulder on the end of the mandrel, and by the motion of turning round in the direction in which the lathe works, the chuck is screwed fast against the shoulder; or the neck of the mandrel may be perforated and cut with an internal screw, an external screw being attached to each chuck. The other end of the mandrel is supported by a point or in a collar. When made with a pointed end, the point is received by the end of a screw tapped through the part D of the frame of the mandrel in the place of the end *a*. By turning this screw the mandrel can be adjusted. The mandrel is turned round by a cat-gut band, passing round the pulley *h*, and the large iron foot-wheel H attached to the end of the axis I. This axis has a crank in the middle, which is united by an iron link K to the treadle L. The treadle is fixed by 3 rails to an axis M, on which the treadle moves. The wheel H is heavy in the rim, and, being firmly fixed to the axis I, turns round with it: the momentum acquired by the wheel is sufficient to turn the work while the crank and treadle are rising. When the crank has passed the vertical position, and begins to descend, the workman presses down the treadle, which gives to the wheel sufficient impetus to bring it round to the same point. The link K must be of such a length that when the crank is in its lowest position the board L of the treadle shall be 2 or 3 inches from the floor. The lathe is set in motion by moving the wheel by hand until the crank has just passed over

its highest point; the motion can then be continued by the foot. The man must stand steady before his work, and not move his body while his foot rises and falls with the treadle. The band which communicates motion from the great wheel to the small one should be of strong cat-gut, united by means of a hook and eye of iron, and furnished with a screw. The cat-gut is to be slightly tapered off at each end by a sharp knife so that it will just enter the hook and eye: the band is then held firmly in a vice in the left hand, and the hook and eye are taken up in a pair of pincers held in the right hand, and are screwed upon the cat-gut until quite firm. This is a better method of joining than others which are usual. The rest N is fixed to the bed by its foot, which is forked so as to receive a screw-bolt which passes down through the lathe-bed and secures the rest at any point of the bed by a nut *k*. The groove in the foot allows the rest to be moved to and from the centre of the work, so as to adjust it to the required diameter of the work. The rest may also be adjusted as to height by making the piece on which the tool is laid with a shank, shaped like the letter T, the shank being a round pin passing into a socket in the foot of the rest, and held at any required height by a clamp-screw N. In turning cones or similar work the edge of the rest M, Fig. 2197, is placed inclined to the axis of the work. Rests are made of different sizes to suit different kinds of work. There is also a *circular* rest, which enables the turner to ornament balls, spheres, and round objects.

The tools used by the turner are gouges and chisels of various sizes and forms. The gouges are first used to rough out and form the wood, and the chisels to smooth it and reduce it to the required form. The

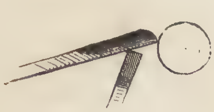


Fig. 2196.

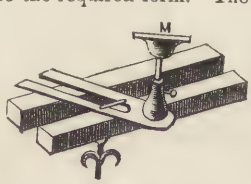


Fig. 2197.

blade of the gouge is formed nearly half round to an edge, and the two extreme ends of this edge are sloped off a little, so that there may be no corners to catch in rough wood. The blade of the gouge is held considerably inclined, as in Fig. 2196, so that the bevel or outside of the edge may form nearly a tangent to the circumference of the work, and the cutting edge be above the level of the centre. The chisels are usually ground with a bevel on either side. In some cases the line of the edge is inclined to the direction of the blade; or it may be rounded to a semicircle, or made with angular points like spears. In using chisels, the rest is raised considerably above the centre of the work, and the line of the cutting edge is made oblique to the axis of the cylinder, to prevent either angle of the chisel from running into the work. The chisel must be gradually traversed along the work. For turning hard woods, ivory, and bone, the points or cutting edges of the tools are bevelled on one side only, and the angle of the edges is obtuse. The tools require frequent sharpening with a grindstone and hone.[1] The turner also uses callipers for inside and outside work, Figs. 2198, 2199, and guages to regulate the dimensions of his work, and he has a great variety of chucks. Those of wood are usually hollowed out, and the work is jambed into the cavity. The turner also uses certain small tools called *milling tools:* they are small wheels, on which a pattern is cut, and being pushed close up to the wood, a few turns of the lathe impresses the pattern clearly upon it.

Fig. 2198.

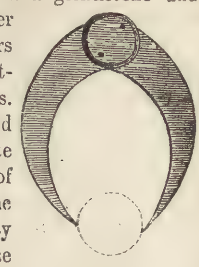


Fig. 2199.

The wood to be turned is rounded with a small hatchet, or with a plane or rasp before it is put into the lathe. The true centres of its two end surfaces must also be found, so that they may be exactly opposite each other when the centre points of the puppets are applied to them. To find the centres lay the piece of wood to be turned upon a plank; open a pair of compasses to nearly half the thickness of the piece; place one of the legs of the compasses on the plank, and let the point of the other describe an arc on one of the ends of the piece when laid flat on the plane of the plank like a roller. Turn the piece one fourth round and describe a second arc; turn it another fourth and describe a third arc; turn it again and describe a fourth; the point within the intersections of these arcs will be the centre of the end. The centre of the other end may be found in a similar manner.

When the work is turned and the ends made flat it is polished. The polishing material for soft woods, such as pear-tree, hazel, maple, &c. is shark skin or Dutch rushes. Ivory and horn are polished with pumice-stone or chalk: the metals with tripoli and putty-powder, and so on.

A convenient form of chuck is shown in Figs. 2201, 2202. It can be screwed to the mandrel at *a*. There is a hole in the centre of it at *b*, for the reception of the piece of wood or ivory which is to be turned. The chuck is divided at the end *b* by two

(1) The most complete and admirable account of the tools used in the various descriptions of turning will be found in the three published volumes of Holtzapffel's "Mechanical Manipulation." The premature death of the author leaves a blank which will not be easily supplied, since it unfortunately happens that those gifted men who have passed a life-time in the engineer's workshop, are not willing to submit to the labour of reducing their knowledge to writing, even if they have the power. Mr. Holtzapffel was a good writer as well as a first-rate mechanician. His work was to have extended to 6 volumes, the fourth being on "The Principles and Practice of Hand or Simple Turning;" the fifth, on "The Principles and Practice of Ornamental or Complex Turning;" and the sixth, on "The Principles and Practice of Amateur Mechanical Engineering." We are glad to hear that the author has left copious notes for the three remaining volumes. Let us hope that they may be worked up by the friendly and competent hand of some brother engineer.

saw-kerfs at right angles to each other as shown in Fig. 2201, by which means the end expands a little and holds the work fast, and further to aid this, the outside is made to taper slightly, and is furnished with a hoop or ferril which on being driven up closes the 4 segments and binds the work. Fig. 2200, is a brass box *b*, which screws to the mandrel at *a*, and holds a wooden chuck which is thus prevented from splitting. It is usual, however, to smear the work with a bit of chalk to prevent it from slipping in

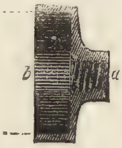


Fig. 2200.

Fig. 2201.

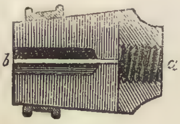


Fig. 2202.

common *cup* chucks; or a thin piece of paper may be inserted between the work and the chuck. Figs. 2203, 2204, are forms of chucks for centre work, the points *c b c*, Fig. 2203, or the point *b* and the chisel edges *c c*, being useful for holding the work.

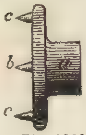


Fig. 2203.

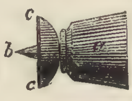


Fig. 2204.

Fig. 2202 is used for holding the balustrade which is being turned in Fig. 2195. When a piece of metal-work is turned between centres, a small chuck with a square hole is used at one end, and the work has a square filed on it to fit the chuck: the other end of the work is supported by the back centre. When great accuracy is required, as in turning arbors, screws, axes, spindles, &c. a chuck, Fig. 2205, is screwed to the mandrel at *a*, while at *b* is a steel centre point exactly in the centre line of the mandrel; the work is

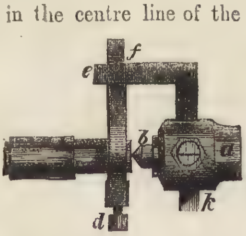


Fig. 2205.

Fig. 2206.

mounted between this point and the point at the back centre, and the motion of the mandrel is imparted to the work by means of a driver, Fig. 2206, screwed to the end of the work and consisting of an iron ring with a screw *d*, tapped through one side of it and made tight upon the work, so as to prevent its slipping round; on the opposite side of the ring is a projecting tail *f*, Fig. 2205, which fits into a claw *k e* passing through the chuck and fastened by a screw: the stem *k* is also adjusted in the socket of the chuck by means of a screw. It will be seen by the form of the driver, Fig. 2206, that the angular shape of the side opposite to the screw allows different sizes to be used in the same ring. To prevent the screw from bruising the finished end of the work, a piece of iron may be interposed between the screw and the work. Iron or steel must be very accurately adjusted in the lathe previous to turning, and when the points of adjustment are found, holes are drilled at the two extremities of the work for the reception of the points of the lathe. The tools used for turning metal are very different from those used in turning wood.

Different substances require different velocities of motion in the lathe to be acted on properly. Wood can scarcely be made to move too quickly, but the shavings should be thin. Brass and bell-metal may be moved quickly, but not with half the velocity of wood. Wrought-iron and copper must be turned more slowly, and the tool kept cool by means of water trickling on it. Steel should be moved with some what less velocity than wrought-iron: it is liable to have hard veins in it, which the workmen call *pins*, these will be cut through if the work move slowly, but if a quick motion be attempted, they will destroy the edge of the tool. Cast-iron must be moved the slowest of all. The different degrees of velocity are obtained by the foot-wheel of the lathe, Fig. 2195, having grooves of different diameters, and the mandrel pulley *h* has also different sizes. By shifting the band to different grooves the velocity may be regulated.

In cutting screws at the lathe a pattern screw *a*, Fig. 2195, is fitted to the end of the mandrel, for which purpose the mandrel is fitted in a collar at each end, and the necks are cylindrical so as to admit the mandrel moving endways at the same time that it turns round. On the extreme end of the mandrel beyond the collar D, the pattern screw is fixed; the distance of its threads corresponds with the screw intended to be cut upon the work, and which is fixed in the lathe by a chuck: at *n* is a piece of brass cut with threads adapted to the pattern screw, and which can by turning a screw be drawn up against the pattern screw so as to work in its threads. In this condition the mandrel in turning round will also move endways in its collars with a screwing motion, so that if a cutting tool be firmly held to the work in one position, it will cut a spiral channel or screw upon its circumference. This is a more accurate method than cutting screws *flying*, as it is called, with the tool, Fig. 2207, applied to the work and moved along endways while the work turns round so as to cut a spiral. Outside and inside screw tools are used in fitting the screw top to a turned box, &c.

Fig. 2207.

In order to form ornamental patterns on the work, various chucks are employed, all of which screw on to the nose of the mandrel, so that one lathe suffices for various kinds of work. With the *concentric* or common chuck, as already noticed, all the articles turned are circular, and the lines which form the circles are enlarged or diminished according as the tool approaches or recedes from the axis. By means of the *excentric* chuck the patterns are still of a circular form, but the centre of the work can be shifted at pleasure. The *oval* or *elliptic* chuck designs oval or elliptical figures. The *geometric* and *compound excentric* chuck produces beautiful geometric

and curved designs. The *oblique* and the *epicycloidal* chucks also turn curious and intricate patterns, and the *straight line* chuck performs all its work in straight lines. Many of these chucks are complicated and consequently very expensive. One of them, of peculiar form and very intricate, is employed for designing patterns on country bank notes and cheques, in order to prevent them from being fraudulently imitated.

The ingenious author of the "Handbook of Turning," (1842,) remarks that there are two points of perfection in the art; one, where the extreme delicacy or elegance of the object renders it admirable, and the other, where it is difficult of execution; and in general turned works are admired by amateurs in proportion as they are opposed to the circular figure. "Those who are very learned in this art can, out of a piece of ivory or mother-of-pearl, produce in the lathe beautiful brooches, ear-rings, and studs, worked in raised flowers, chess-men in imitation of carving, and ornamental vases full of detached flowers; while fluted and spiral columns, delicate mouldings and fanciful beadings, are of comparatively easy execution."

The *excentric* chuck is a very useful appendage to the lathe. By its means the turner can change the centre of his work at pleasure, and produce a great variety of circular lines of varying size, together with other ornaments. In turning patterns, however, the tool should be held in a sliding or parallel rest, otherwise exactness and delicacy of work cannot be ensured. Moreover, with the excentric chuck, the slide rest marks the size of the circles, while the chuck fixes their positions. The excentric chuck is represented in two positions in Figs. 2207, 2208. *a* is a socket for screwing to the mandrel; *b b* the chuck, formed in the same piece with the socket *a;* in front of the chuck is a dove-tailed groove, formed by two pieces *d d* screwed to the chuck: in this groove is fitted a slider *e e*, to which a centre pin is fixed, and a circle *f* fitted to the centre pin so as to turn round freely. A screw *g* projects in front of the circle for fixing chucks thereto. A screw *k* allows the slider to be gradually moved in the groove, but retains it firmly in the position in which it is placed. By means of this screw the centre pin of the circle *f* can be made either to coincide with the line of the mandrel, or it can be set with any required degree of excentricity from the mandrel, as is shown in Fig. 2209, by the difference between the line of the screw *g* and that of the socket *a*. The circle is divided round the edge with equidistant notches or teeth; and a tooth or catch *h* is fitted on the slider by a centre screw, and has a tooth which can be inserted into any of the teeth at pleasure, so as to prevent the circle from turning round upon its own centre pin. The work which is fixed to the screw *g* will evidently turn round with the mandrel. Now when this chuck is screwed to the mandrel by the internal screw at *a*, the screw *k* is turned until *g* is brought exactly into the line of the mandrel. A wood chuck is next screwed on at *g*, and the work fitted to it and turned to its required figure as in ordinary turning. The face of the work is then ornamented by tracing a number of circles upon it. The screw *k* is first turned until the centre of the circle *f* is removed to a given distance from the line of the mandrel; the tool in the slide-rest is then brought up to the work, and a fine circular line cut. Such a circle is evidently not in the centre of the work, but removed therefrom to a distance equal to the degree of excentricity given to the slider. One circle having been described the lathe is stopped, the catch *h* released, the circle *f* moved through the space of one tooth or notch. The lathe is again put in motion, and another circle described by the point of the tool held in the same position as before; but the circle thus described will fall on a different part of the work to the circle first described, but its centre will be at the same distance from the centre of the work. On stopping the lathe and turning the circle *f* round another tooth, a third circle is described, and when as many circles have been described as there are teeth in the circle *f*, the ring of circles is complete. It will contain as many circles as there are divisions in the circle *f:* they will all be of equal size, and their centres arranged at equal distances round the centre of a small circle which is concentric with the work.

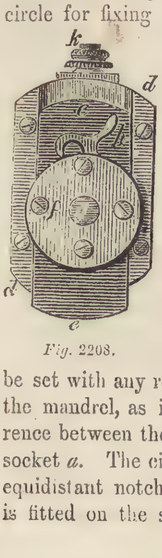


Fig. 2208.

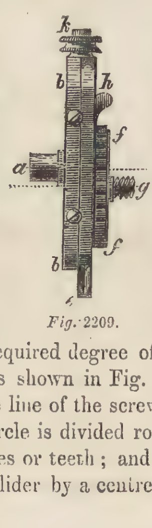


Fig. 2209.

A small instrument called an *excentric cutter* is often used by the ivory turner. It may be formed like a drill-stock, and is moved by a bow; but the cutting point can be fixed at different distances from the centre by means of a groove and screw. When used with the click-plate on the mandrel, it can be employed for ornamenting the sides, edges, or curved surfaces of work. The excentric cutter and the method of using it with the *overhead frame*, are thus described in the "Hand-Book of Turning." "The excentric cutter, Fig. 2211, fits into the sliding-rest, but now it is no longer the work which moves round while the tool is stationary, but the wood remains fixed while the tool rapidly revolves and cuts the patterns. For this purpose it is obviously necessary that the fly-wheel should turn the cutter while the small wheel remains immovable. Several methods are used to perform this, but the one given in Fig. 2210 is the easiest. The frame here represented should be of iron, firmly screwed to the bench of the lathe, and of sufficient height to be about a foot above the head of the workman. In front is a spindle which works in 2 nuts 1, 1, exactly in a line with the mandrel. Two wooden wheels 2, 2, are fastened to this spindle, the one on the left hand remains stationary over the fly-wheel of the lathe, by which it is turned, the other slips backwards and forwards,

according to the work it is required to do. Take off the usual cat-gut from the fly-wheel, and pass a long one over it and over the small wheel on the over-

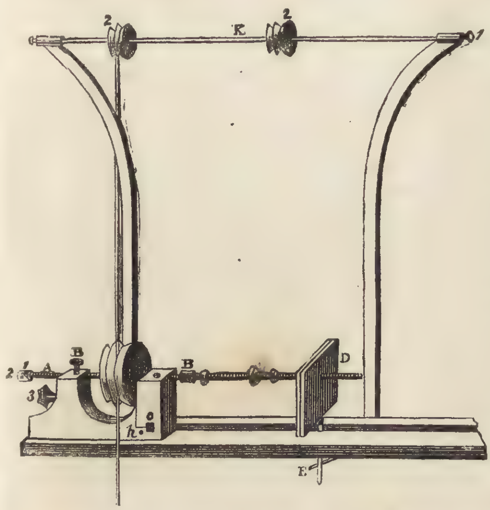


Fig. 2210. OVERHEAD MOTION.

head frame No. 2. When the cutter, Fig. 2210, is fixed in the slide rest, draw the other small wheel No. 2 on the spindle K, forward, till just above the rest, then pass a cat-gut over it and round the small brass wheel B of the cutter, and the whole will turn together. The brass wheel of the lathe must then be fixed at one particular number. It is usually divided into 360 parts, each marked by a small hole, and it is by properly dividing the numbers on this plate that the accuracy of the patterns depends. To keep the wheel steady, a small steel key *h*, Fig. 2210, is slipped into the brass knob *o*, and the other end being pointed enters into one of the small holes, and the work is immovable until the key be moved into another hole. The cutter, Fig. 2211, is of brass, with a spindle C, which works in 2 brass collars K. At one end is the wheel B, by which it is turned; at the other a steel frame D D, which is marked on the upper edge in

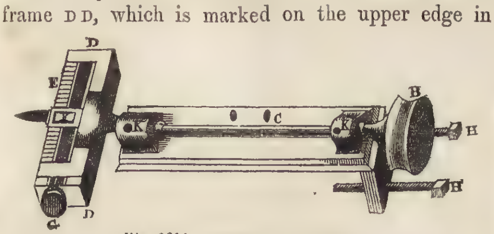


Fig. 2211. EXCENTRIC CUTTER.

small lines E to regulate the quantity of excentricity. The steel tool-box F holds the tool, which is kept firm by a small screw beneath. By means of a screw through the frame D D, the tool is pushed backwards and forwards, and cuts a large or a small circle. G is the nut that moves it, and it also is divided into numbers. The cutter for many patterns is quite as useful as the excentric chuck, but in conjunction with the former it is invaluable, and the patterns performed by them may be multiplied according to the taste and genius of the turner. The 2 screws H H fix the depth of the cut; the wheel of the slide-rest determines the necessary distance, that of the cutter the excentricity, while the brass wheel keeps the pattern accurate. The tools used are of various forms and sizes."

Oval, or as it is more properly called *elliptic turning,* (for an oval is smaller at one end than the other,) is performed by means of a chuck of peculiar construction. The oval chuck (the invention of Abrâham Sharp,) consists of three parts, the *chuck,* the *slider,* and the *excentric circle.* The chuck is secured to the mandrel by a screw socket cut in a piece *f,* Fig. 2215, which projects from the centre of it behind, so that the chuck partakes of the circular motion of the mandrel. In front of the chuck is a dove-tailed groove formed by the pieces *i i,* Fig. 2314, for the reception of a slider *g h,* from the centre of which projects a screw *h* for the reception of a wooden chuck which holds the work. By this arrangement the work in turning round by the motion of the chuck has a sliding motion across the centre, by which means an ellipse is generated. This sliding motion is given by means of the excentric circle, Fig. 2212, or ring of brass fastened to the puppet of the lathe close to the collar in which the neck of the mandrel runs. The mandrel passes through the aperture *l:* the flat plate *m,* which strengthens the ring, has at each end a bend *m* with a screw in each exactly opposite each other: the screws have sharp points for insertion in small holes in each side of the puppet as at C, Fig. 2213, the back of the plate *m* of the circle lying flat against the front of the puppet C; by which means the circle is fixed. The 2 screws are horizontal, and both point to the centre of the mandrel *b;* so that by screwing one screw in and the other out, the whole circle may be moved sideways horizontally, so as to give the required degree of excentricity from the centre line of the mandrel, and it will be held stationary wherever it is placed. The back of the chuck, Fig. 2215, shows 2 grooves made through it in the direction of the length of the slider, for admitting the shanks of 2 pieces of steel *n n* to pass through the chuck; they are attached to the slider *g* by screws in front, as shown in Fig. 2214. The two inside edges of *n n* are

Fig. 2212.

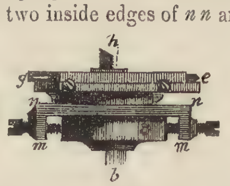


Fig. 2213.

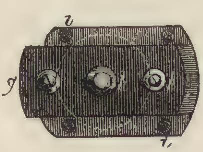


Fig. 2214.

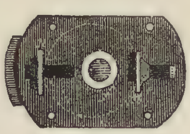


Fig. 2215.

parallel to each other, and the distance between them is equal to the diameter of the outside of the ring, Fig. 2212, the ring being included between them when the chuck is screwed to the mandrel *b,* and the

circle fixed to the puppet C as in Fig. 2213. Now if the circle be set concentric with the mandrel, the chuck, the slider g, and the work attached by the screw h will all be concentric, and circular work will be turned, the slider being guided by its claws $n\,n$, which embrace the circle. In order to set the work for an ellipse the point of a tool in the slide-rest is placed opposite the work, so far from its centre that it will describe a circle of a diameter equal to the breadth or smallest diameter of the intended ellipse. The mandrel is now turned until the slider g is horizontal; the circle is then set excentric from the mandrel by means of its screws $m\,m$, by which means the slider g will be moved in the groove of the chuck, but the work will be moved with it to a greater distance from the centre, because the 2 steel pieces $n\,n$ include the whole circle between them. "The quantity of excentricity given to the ring must be equal to the difference between the two diameters of the required ellipsis, so that the work shall move or throw out a sufficient distance to bring the point of the tool as much beyond the circle first described, as the length of the ellipse exceeds the breadth. The point of the tool will now be at one end of the longest diameter, and here we will commence to trace the curve all round. In turning the mandrel round till the slider becomes vertical it must return in its groove to the place it first occupied, viz. the centre; because the excentric circle which guides the slider is not excentric in a vertical direction, though it is in a horizontal. In this motion the point of the tool has cut or described one quadrant of an ellipse, because it gradually approached the centre a quantity equal to the excentricity of the circle. By continuing to turn the mandrel round further, the circle will cause the slider to move out the other way from the centre in its groove until it comes again horizontal, when it will be at the greatest *throw out*, as the turners term excentricity, and the point of the tool will be at the other end of the longest diameter, having described one half the curve: continuing to move forward till the slider becomes vertical, it will become concentric again, and the tool will be at the breadth of the ellipse, having finished three quarters of the ellipse; and in turning the next or fourth quarter, the slider throws out till it comes horizontal, and brings the work to the position where we first set out, viz. at its greatest excentricity; and with the tool at the end of the longest diameter of the ellipse." [1] This chuck is sometimes provided with a click, or even with a micrometer plate, for placing the ovals in different directions. The oval and the excentric may also be combined in one chuck.

Rose-engine turning requires a particular adjustment of the lathe in addition to special chucks for the production of those patterns of curved lines called by the French *rosettes*, from the slight resemblance which they bear to a full-blown rose, and hence the term *rose-engine*. The rose-engine lathe differs from the common lathe in this, that the centre of the circle in which the work revolves is not a fixed point, but is made to oscillate with a slight motion while the work is revolving upon it, the tool being all the time stationary, and hence the figure will be "out of round," as the turners call it, or will deviate from the circular figure as much, and as often, as the motion is given to the centre. See Fig. 2216.

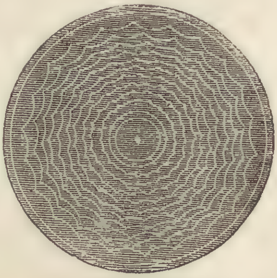


Fig. 2216. THE ROSE.

All work which is to be figure-turned must be held in a chuck screwed on to the end of the mandrel T, Figs. 2217, 2218, which being movable, gives those deviations from the circular form required to form the figured work. For this purpose, the two standards G H, which support the mandrel, are not firmly fixed to the bed A, as in other lathes, but they descend between the cheeks or cast-iron bed almost as low as the bottom of the mahogany bed A, where they are united by an axis P, which is parallel to the mandrel, and supported on pivots at its ends, which pivots being received in pieces of cast-iron descending from the cheeks, and strengthened by an iron bar Q extended between them. The two standards G H are formed of one piece, and have a strong bracing of iron between them.

The work is fixed in a chuck at the extremity of the mandrel, and the tool is held by a slide-rest and adjusts it to the radius of the rose or figure intended to be cut. The oscillating motion is given to the mandrel by means of metal rosettes or wheels fixed upon the mandrel, each having its edge or periphery indented and curved with a waving line, as shown in Fig. 2118. The rosettes are acted on by a small roller at the end of the piece n, which is supported by a triangular bar m fixed parallel to the mandrel upon the upper end of curved arms. When the mandrel revolves, the eminences and depressions of the rosette applying themselves to the roller, which moves on a stationary axis, will cause a vibratory or oscillating motion of the mandrel and of the frame G H, Fig. 2217, which contains it. Within the cavity of the bed A is a strong spring, applied to the frame of the

(1) "Rees's Cyclopædia." There are several excellent articles on *Turning* in this work, to which we have been considerably indebted in the preparation of this article. But as these articles are not accessible to the general reader we would recommend a work among the Manuels-Roret, entitled "Nouveau Manuel complet du Tourneur." Par E. de Valicourt, 3 vols. Paris, 1848—1853. This work is chiefly compiled from the celebrated treatises of Plumier, Bergeron, Desormeux, Dessables, Mapod, and others, which have long been out of print. With the exception of the "Hand-book of Turning," there are very few works in English on this important art. In 1817, "Specimens of Excentric Circular Turning," was published by John Holt Ibbetson, Esq.; and in 1825, a second edition of the same work; and in 1838, a third edition, greatly enlarged. In 1833, Mr. Holtzapffel published an account of Ibbetson's Geometric chuck, with specimens. In 1819, Mr. C. H. Rich, of Southampton, published "Specimens of the Art of Ornamental Turning;" and also "Tables by which are exhibited at one view all the divisions of each circle of the dividing plate." The *Mechanic's Magazine* also contains a number of valuable articles on turning.

mandrel, to restore the latter to a central or vertical position when disturbed therefrom by an indentation in the rose. The mandrel M contains 17 rosettes of different patterns. Several are scolloped out like Fig. 2218, but the number of waves or scollops differs from 12, as in the figure, to 144. The socket for the piece *n* can be fixed by its clamp-screw upon any part of the triangular bar *m* in order to bring it opposite any one of the rosettes which it is required to use. Other

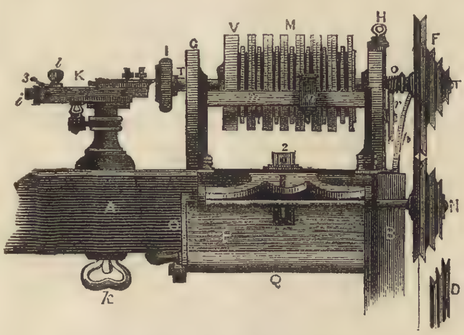


Fig. 2217. ROSE-ENGINE LATHE.

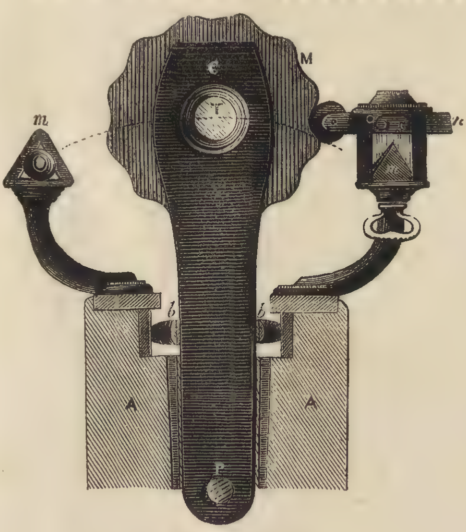


Fig. 2218. ROSE-ENGINE.

rosettes are furnished with convex protuberances. In either case, if the pattern be fine, the wheel on *n* is not used, but the opposite end of *n*, which is rounded, hardened, and polished, to diminish as much as possible the friction of the revolving rosette. The engine is not moved with the foot, but by means of a hand-winch, O, Fig. 2217, fixed upon the end of a spindle, which at the other end carries a small wheel N, communicating by a band with the great wheel. The spindle is supported in a frame attached to the lathe-frame by a centre or joint on which it can be raised up and fixed by a toothed sector to tighten the band when required.

By means of a *straight-line* chuck, the patterns of the rose-engine are made to follow a straight instead of a circular direction.

A *slide-rest* is now attached to all lathes except those of the most ordinary kind. There are various forms of this most useful instrument, one of which is represented in the INTRODUCTORY ESSAY, Fig. lxvi., where it is applied to the turning of iron. Another form is also shown in the steel engraving which accompanies the article SCREW. It is also shown in its proper position in the lathe in Fig. 2217, but in the foregoing examples it is introduced as a subsidiary piece of apparatus. We will now describe it more specially. The foot of the rest is formed with a dovetailed groove, into which the head of a screw bolt fits, and passing down through the bed is fixed in any part by means of a thumb-nut *k*, Fig. 2217. The groove in the foot allows the rest to be moved to and from the centre of the lathe to adjust it to the diameter of the work. At the end of the foot is a cylindrical pin fitting into a socket S, Fig. 2219, formed solid with the lower slider K of the rest: the socket is held fast upon the pin by means of a clamp-screw: at the bottom of the socket is a notched wheel *s*, and a catch *t*, fixed to the foot R to engage the teeth or notches, by which means the sliders K can be held fast at any required angle with the mandrel. The upper part of the slide-rest consists of two horizontal sliders, K and *g*, placed perpendicularly to each other:

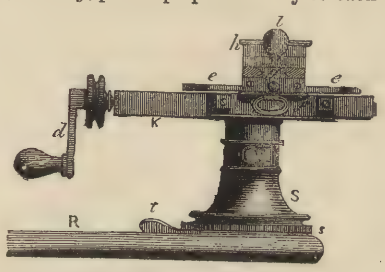


Fig. 2219. SLIDE-REST.

the tool is attached to one of these, and by means of screws with handles the sliders and the tool can be moved in any direction. K is a metal frame formed from the same piece as the socket *s*: its upper surface is flat, and on this a slider, or flat plate *e e*, is fitted so as to move with ease and precision. In the opening of the frame K is mounted a screw, tapped with a piece of metal projecting from the lower side of the slider, so that when the screw is turned round by the handle *d* fitted to its square end, it advances or draws

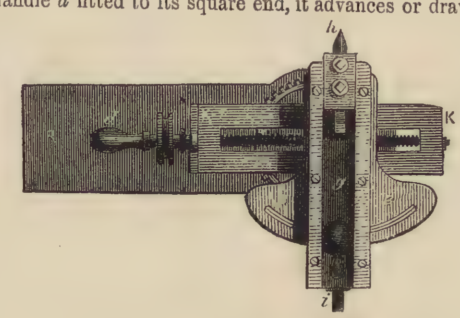


Fig. 2220. PLAN OF SLIDE-REST.

back the slider, which is guided in a right line by two pieces of brass on its under side, forming a dovetailed groove to which the edges of the frame K are

accurately fitted. On this slider a frame or two rulers are fixed, with a second steel slider *g* fitted in the dove-tailed groove between them, and moved by a screw *i*. This upper slider has a piece of metal with a square hole through it, in the direction of its length, for the reception of the tool *h*, and it is secured by a screw at the top. When the slide-rest is mounted on the bed of the lathe, as in Fig. 2217, the upper slider *g* is parallel with the mandrel, and the lower one perpendicular thereto. In turning flat or face-work, the tool is placed as represented. By turning the screw *i* of the upper slider the tool advances up to the work, and by means of the other screw *d* it can be moved across the face of the work, thus producing a perfectly flat surface. In turning a cylinder, mounted between centres, the slide-rest is moved one-quarter round upon the pin in the socket s, so that the upper slider will be perpendicular to the mandrel, and the lower one parallel to it. In such a case the upper slider must be moved to adjust the tool to the diameter of the work, and the lower slider is moved by its handle *d* to carry the tool along the length of the cylinder. In turning a cone, the plate or dove-tailed groove, which supports the upper slider *g*, is turned round upon the plate *e e*, and fastened at any inclination by a screw passing through a circular groove in the plate. In this way the upper slider is inclined to the mandrel in any required angle, and will turn a cone either hollow or solid. The sliders are often divided into inches and parts, by which means the work can be made to any required dimensions, and articles turned to pattern without difficulty. The upper slider *g* has a graduated arc for showing the angle of inclination which it makes with the lower one when set for turning cones; so that a hollow cone, being bored out in a chuck, a solid plug may be bored to fit it without any further adjustment.

In engine-turning, the slider *g*, Fig. 2220, with the tool is advanced to the work by pressing it with the hand instead of the screw. For this purpose the slider is released from the nut of the screw *i*, Fig. 2220, by lifting up a small spring catch 3, Fig. 2217, the tooth of which enters a notch in the nut, and is pressed into the notch by a screw *l*, by releasing which, lifting up 3, and drawing back the slider, the tooth of the catch falls behind the nut of the screw instead of being in the notch; it thus forms a stop to check the advance of the tool, but allows it to be drawn back to clear the work, and also to be pushed in towards it by hand to cut the line, the stop regulating the depth of the line, as the hand can advance the slider no further when it meets the nut. In this way a waved line is engraved on the face of the work, the breadth of the line being determined by the depth to which the point of the tool is regulated. The outer waved circle being formed the tool is withdrawn, and the screw *d* of the great slider turned a small quantity, so as to bring the point of the tool a little nearer the centre of the work; by putting up the tool another line is described; and in this way the process is repeated until the lines reach the centre. As each line has the same number of waves or indentations they become very fine as they approach the centre; but as the deviation from the circular figure is equal in the small as in the large rings, the curves of the waves of each ring or line gradually vary, being slightly curved near the edge of the work and much more so towards the centre. This pattern may be greatly varied by employing different rosettes, fine or coarse, concave or convex, but the waves will always be in radial lines. A variation in this respect is made by turning the rosettes upon the mandrel through a very small space after the cutting of every line, a small screw H, Fig. 2217, being provided for the purpose. Fig. 2216 is an example of this movement; it is a rose of 24 waves: after cutting the exterior line, and the slider has been set for a second line, the rosette is turned round upon the mandrel a quantity equal to $\frac{1}{4}$ of a wave or $\frac{1}{96}$th of the whole circle: the circle is then described, and its waves will not fall into the radial lines of the former, but a little in advance thereof. The next time a circle is cut the rosette is again shifted, and so on. As this is a quantity equal to $\frac{1}{4}$ of the space between the waves, the waves of every fourth line will fall into radial lines. The concentric circles are made at equal distances by means of the divisions on the slider K, Fig. 2217, or by divisions made upon a head fitting upon the end of the screw *d*, and the rosettes are set exactly to the quantity they are intended to be turned round, by means of divisions made upon the edge of a circular plate fixed upon the mandrel towards the end of H, Fig. 2217, a line or mark upon the last rosette applying to it. The screw which produces the movement is supported in bearings upon this plate, and acts in the teeth of a wheel fixed within the hollow of the last rosette. By this means the screw is turned round by a key, and all the rosettes are thus made to turn together through any space, as indicated by the divisions on the circle. It is surprising what a number of patterns can be produced by this simple contrivance of shifting the rosettes in various ways. For example, after having cut a waved line, the rosette may be advanced half a division and another line cut without altering the slide-rest. The two waved lines will thus intersect each other and make a number of loops like a chain of beads.

In ornamenting the surface of a cylinder, the slide-rest is turned $\frac{1}{4}$ round; by dividing the length of the cylinder into small equal portions and shifting the rosettes every time one of these is finished, the waves may be made to follow each other in a spiral direction round the cylinder. Some of the rolls used in calico-printing are in this way engraved in the lathe.

There is a movement of the rose lathe called *pumping*, in which the mandrel is made to move endways upon its bearings, for which purpose the necks upon which it turns are made truly cylindrical and fitted correctly to steel collars fixed in the standards G H. It can thus slide endways in its collars so as to produce the pumping motion which is given by rosettes waved upon the edge or side, and acting against the

side of a piece of steel as *n*, Fig. 2218. A spring *p*, Fig. 2217, is fixed at the end of the frame and acts against the shoulder of the mandrel, to force it endways, and keep the rosette always in contact with the piece of steel. The rosettes are cut in waves upon their sides as well as upon their circumference, and thus a variety of pumping rosettes is obtained. By this pumping motion waved lines can be cut upon the surface of a cylinder in the direction of its length.

Screw tools formed like a chisel, but with the edge cut with notches so as to present a number of points, are sometimes used for the sake of expedition, so that 6 or 8 lines may be cut at one operation without altering the slide-rest after every single line is cut.

In cutting *swash-work*, in which the mouldings or other lines traced round a cylinder are inclined to the axis, a steel circle or hoop v, Fig. 2217, is fitted to the end rosette of the mandrel, so that it can be inclined from the perpendicular thereto at pleasure. In this way it forms a guide to the pumping motion.

TURNSOLE. See Litmus.

TURN-TABLE. See Roads and Railroads, Fig. 1885—1888.

TURQUOISE, a mineral of a blue or greenish blue colour, occurring in botryoidal or mammillated masses, chiefly in alluvial clay in Persia. It has a conchoidal fracture, and a waxy lustre; it is capable of receiving a high polish: it is usually opaque, but sometimes translucent on the edges: hardness 5 to 6, density 2·8 to 3. It contains phosphoric acid 30·90 per cent., alumina 44·50, oxide of copper 3·75, oxide of iron 1·80, water 19. This is the *oriental* turquoise: the *occidental* or *bone* turquoise, (which is chiefly found near the town of Simore in Lower Languedoc,) is said to consist of bone or phosphate of lime, coloured with oxide of iron. A specimen analysed by La Grange contained phosphate of lime 80 per cent., carbonate of lime 8, phosphate of iron 2, phosphate of magnesia 2, alumina 1·5, water 1·6. Green malachite is sometimes substituted for the true turquoise; but it is softer, and has a different tint. The stone is also so well imitated by the makers of factitious gems, that it is difficult to detect the counterfeit from the original; the former, however, is much softer than the latter.

The mines of the true turquoise are in Khorasan, at the south-east of the Caspian Sea, in a mountainous district, about 40 miles west of the town of Nishapore. They were visited by Mr. Fraser, some years ago, and from his notice [1] it appears that the turquoise has been found only in one hill, and this has been opened in six places. The first mine does not produce fine gems; in it is a bed of light grey porphyritic earth, which is turned over, and pieces of turquoise are found attached to fragments of porphyritic rock. The second mine consists of porphyritic rock, tinged with iron, and containing small veins of blue turquoise matter, chiefly between the laminæ of the rock. Small pieces of the gem are found adhering to the rock, and in some places the turquoise seems to have bubbled out from the rock in the form of little pimples of exquisite colour. The third mine was not worked at the time of Mr. Fraser's visit. There was an efflorescence of alum on the face of the rock. The fourth mine consists chiefly of two deep excavations in a dark brown rock, through which the turquoise matter is disseminated in small veins. One of the excavations was full of water, which the miners did not appear to know how to get rid of. The fifth and most important mine is near the summit of the hill; in this the turquoise pervades a porphyritic rock, and is also found in an imperfect state in a yellow ochreous clay. In this mine the gem is found in tolerably symmetrical nodules of different sizes, in narrow veins pervading the rock, and in irregular masses, generally of inferior quality. The sixth mine appeared to be exhausted. The mines are described as being worked in a very slovenly manner; there are no shafts or galleries, but each man gropes about according to his own judgment, and leaves the rubbish of the mine in the places where it is produced. The mines are the property of the crown, and are farmed out at a sum named by the government. In 1821, it was about 2,700*l*. They are generally taken by the inhabitants of two villages near the mines. The mode of working is as follows:—100 villagers take the mines at a price agreed on, and work together in parties of 5 or 10, who divide the produce of their labour collectively or by these separate parties, each man contributing his share of the rent of the mines. The produce is sold to merchants who visit the villages at stated periods, or it is sent to the town of Mushed for sale. The gems are sold in 3 different states. 1. As single stones, freed from the parent rock and ground, so as to expose the size, shape, and colour of the gem. 2. Stones freed from the principal part of the parent rock, the gem being only partially visible. 3. Masses containing still more of the parent rock: these are sold by weight.

The stone-cutters reside in Mushed, the chief seat of the turquoise trade. The stones are ground on sand laps of different degrees of fineness, turned by a bow and string, a broad hoop concentric with the lap preventing the sand and water from being scattered over the lapidary, who holds the gem in his hand while grinding and polishing. The gems, which are mostly worked up into rings, are sorted and sent to different countries. The finest find their way to India by way of Herat and Candahar. The next in quality are conveyed westward to Persia and Turkey; or they are sent to Bokhara, and sold to merchants who trade with Russia, and thus they gradually get to Europe. The less perfect gems fetch a much lower price on account of their being covered with small white specks; the Arabs, however, do not object to this defect, as they value the turquoise chiefly for its reputed talismanic qualities, and they prefer large stones to purity of colour. The stones intended for amulets are commonly set in small rings of plated tin. Professor Fischer notices [2] a noble turquoise,

(1) Travels and Adventures in the Persian Provinces on the southern banks of the Caspian Sea. 4to. London, 1826.

(2) Essai sur la Turquoise, 1816.

said to have been a talisman belonging to Nadir Shah of Persia, and containing on its surface a verse of the Koran beautifully engraved; it was in the possession of M. Weyer, a jeweller of Moscow, who demanded 5,000 rubles for it, or about 812*l.* 10*s.* sterling. It is described as a thin plate of exquisite colour, attached to its original matrix, and shaped into the form of a heart.

In the Great Exhibition there was a collection of upwards of 200 turquoises made in 1849 by Major C. Macdonald in Arabia Petræa. We learn from the Jury Report, Class I., that he discovered in the country of Soualby, 16 days' journey S.E. of Suez, 5 or 6 localities in which turquoises existed, all included within a range of about 40 miles. They are situated on the further side of a mountain chain, having an east and west direction, and a mean elevation of 5,000 or 6,000 feet. Most of the specimens were collected from the ravines descending this chain, but some were found *in situ.* The latter were exhibited attached to a portion of the parent rock, which is a reddish sandstone composed of quartz grains. The colour of these turquoises differs in the shade of blue from that of the turquoises of Persia, but agrees exactly with those brought from Abyssinia by M. R. d'Héricourt. Both exhibit small globular concretions, with a hardness equal to that of agate. The nodules of turquoise form groups almost like currant-seeds in the sandstone. The intensity of the colour of adjacent lumps is different, and when the groups are of tolerably large dimensions, zones of different tints may be observed. One stone, *en cabochon,* polished without cutting, was divided into 3 zones, in which the colour varies from an intense blue to a bluish white. Other specimens exhibited veins of turquoise from $\frac{1}{10}$th to $\frac{1}{20}$th inch thick, cutting across the bedding of the sandstone like small threads.

TURPENTINE. When trees belonging to the *Coniferæ* or *fir-tribe,* especially the genus *Pinus,* are wounded in the bark, a balsam exudes consisting of a mixture of resin and a volatile oil. The latter, when separated by distillation, is known as *spirit* or *essence of turpentine* or *terpentine,* and is known in commerce as *turps* or *terps.* The source of common turpentine is *Pinus sylvestris,* and its collection is an important branch of business in America. "To procure it a narrow piece of bark is stripped off the trunk of the tree in spring, when the sap is in motion, and a notch is cut in the tree, at the bottom of the channel formed by removing the bark, to receive the resinous juice, which will run freely down to it. As it runs down, it leaves a white matter like cream, but a little thicker, which is very different from all the kinds of resin and turpentine in use, and which is generally sold to be used in the making of flambeaux, instead of white bee's-wax. The matter that is received in the hole at the bottom is taken up with ladles and put into a large basket; a great part of this immediately runs through, and this is the common turpentine. It is received into stone or earthen pots, and is then ready for sale. The thicker matter which remains in the basket is put into a common alembic; and a large quantity of water being added, the liquor is distilled as long as any oil is seen swimming upon the water. The oil, which is produced in large quantities, is then separated from the water, and is the common oil or spirit of turpentine. The remaining matter at the bottom of the still is the common yellow resin."[1] According to another account, the collection of turpentine in the United States is confided principally to negroes, each slave having the charge of from 3,000 to 4,000 trees. The process is continued through the year, but the incisions are not made in the trees until the middle of March, and the flow of turpentine generally ceases about the end of October. The formation of the cavity at the root of the tree is called *boxing,* and the turpentine which flows into it is known in commerce as *pure dipping.* Each *box* holds about a pint and a half, and is emptied 5 or 6 times during the season: it is estimated that 250 boxes will produce a barrel weighing 320 lbs. The deposit made by the sap on the bark of the tree is called *scraping,* and is collected in autumn. The quantity of turpentine imported into the United Kingdom in the year ending 5th January, 1853, amounted to 481,616 cwt.

There are other kinds of turpentine. That known as *Venice, Strasburg, Swiss,* or *larch* turpentine is obtained from the *Larix Europæa.* It is a clear, colourless balsam, containing from 18 to 25 per cent. of the oil. It has a tendency to thicken or solidify. Professor Brande states that the article usually sold under this name is factitious, and is made by fusing a pound of resin with about 5 ounces of oil of turpentine. There is a thinner *Strasburg* turpentine from *Pinus picea,* containing 33 per cent. of oil. *Canadian turpentine* or *Canada balsam,* the purest of all the pine turpentines, is obtained from *Abies balsamea* in Canada. In its fresh state it has the consistence of honey, an agreeable odour, and a bitterish taste; it is of a yellow transparent colour: it solidifies on being kept. *Chian turpentine* is obtained from the turpentine tree, *Pistacia terebinthus,* a native of Barbary and the south of Europe; this turpentine has a highly aromatic flavour. *Common frankincense* is an exudation of *Abies communis.* The *Carpathian* and *Hungarian* varieties of turpentine are from *Pinus cembra* and *mugo.*

The balsam obtained by tapping pine-trees is, as already stated, a solution of resin in oil of turpentine, which substances have so close a chemical relation that the resin is produced from the turpentine by simple exposure to the atmosphere. Oil of turpentine is regarded as a compound of a carbo-hydrogen with hydrogen, or $C_{20}H_{15}+H$, in which case resin is formed by the abstraction of the single equivalent of hydrogen by the oxygen of the air, water being produced, and the substitution of another equivalent quantity of oxygen in its place. The resin of turpentine is a mixture of two substances of this kind, and is similar in composition to *sylvic* and *pinic* acids, $C_{20}H_{15}O_2$.

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(1) Loudon, "Arboretum Britannicum."

The different varieties of turpentine above enumerated, consist of different proportions of oil and resin. Common turpentine contains from 5 to 25 per cent. of the oil. When this dries up or hardens into resin on the trees it is called pine-resin, or white-resin; it contains about 10 per cent. of the oil; it is hard on the outside, soft within, and it admits of being kneaded. When melted and drained from the particles of wood, &c., the residue is *Burgundy-pitch*, or *cobbler's-wax.*

As the oil of turpentine is of much greater value than the resin, it is separated by distillation in a copper retort, with about one-fourth part of water. When no more oil and water pass over, the melted resin is drawn off and strained. It cools into a brown, transparent, brittle mass, more or less dark in colour, according to the extent to which the distillation has been carried. It is called *colophony.* At the temperature of 156° F. it is sufficiently soft to be kneaded: at 275° it is completely fluid. When heated out of the presence of the atmosphere, it evolves gas, a combustible oil, and an acid water. [See Gas, Fig. 1050.] The density of colophony is 1·07 to 1·08: it consists essentially of pinic acid mixed with a little sylvic; its dark colour is traced to pinic acid, which is readily decomposed into another resin-acid, the *colophonic.* Cobbler's wax is formed artificially, by fusing 3 parts colophony and 1 part of white resin.

Oil of turpentine obtained by the above process of distillation, is rectified by mixing it with a solution of caustic potash, and re-distilling. The product forms *rectified oil of turpentine* or *camphine;* but to obtain it perfectly pure, it must be again distilled with water, and lastly with chloride of calcium. Thus purified, oil of turpentine is a limpid colourless liquid, with a hot taste, and a peculiar odour; its density at 60° is 0·865 to 0·870: it boils at 314°, and the density of its vapour is 4·764. It is almost insoluble in water, and only slightly soluble in spirits of wine. It mixes readily with the fixed oils. It is very inflammable, and burns with a very sooty flame; but if well supplied with air, the flame is very brilliant, and emits no smoke. [See Lamp, Fig. 1270.] The oil thus burned should be pure and freshly distilled, and exposed to the air as little as possible. As oil of turpentine is very inflammable it should not be preserved in wooden casks, (on account of the liability to leakage,) without the precaution of placing each cask within another containing water.

Oil of turpentine is largely used in the arts. See Painting—Varnish.

When rectified oil of turpentine (not made anhydrous) is kept for a long time in bottles, their interior is sometimes studded with groups of beautiful, colourless, prismatic crystals, having the composition of a *hydrate* of oil of turpentine, and containing $C_{20}H_{16}H_6O_6$.

Oil of lemons has the same composition as oil of turpentine, although so dissimilar in odour. The oils of *orange-peel, bergamot, pepper, cubebs, juniper, capivi, elemi,* the *laurel-oil* of Guiana, and the *grass-oil* of the East Indies are hydrocarbons isomeric with oil of turpentine.

Strong sulphuric acid chars and blackens oil of turpentine; concentrated nitric acid and chlorine act with such energy on it as to set it on fire. With hydrochloric acid it forms a substance called *artificial camphor*, from its resemblance to that substance. It is formed by passing dry hydrochloric acid gas into the pure oil kept cool by a freezing mixture. A white crystalline substance separates, and on straining off the supernatant brown acid liquid, it may be purified by alcohol, in which it dissolves readily. It is neutral to test paper; it sublimes without much decomposition; it consists of $C_{20}H_{17}Cl$, or $C_{20}H_{16}HCl$. The dark mother liquor contains a similar but fluid compound. These substances are furnished in very different quantities by different specimens of oil of turpentine. When decomposed by distillation with lime, they give oily products similar in composition to oil of turpentine, but possessing certain distinctive properties. That from the solid artificial camphor is named *camphylene;* and that from the liquid, *terebylene.* Another isomeric compound, termed *colophene*, is formed by distilling oil of turpentine with concentrated sulphuric acid; it is a viscid, oily, colourless liquid, boiling at a high temperature: by reflected light it has a deep bluish tint.

The countries which supply turpentine, furnish also that very important substance *tar.* The process of tar-making in the north of Europe is thus described by Dr. Clarke:—"The inlets of the Gulf of Bothnia are surrounded by noble forests, whose tall trees, flourishing luxuriantly, cover the soil quite down to the water's edge. From the most southern parts of Westro-Bothnia to the northern extremity of the Gulf, the inhabitants are occupied in the manufacture of tar, proofs of which are visible in the whole extent of the coast. The process by which the tar is obtained, is very simple. The situation most favourable to the process is in a forest near to a marsh or bog, because the roots of the fir, from which tar is principally extracted, are always most productive in such places. A conical cavity is made in the ground, (generally in the side of a bank or sloping hill); and the roots of the fir, together with logs and billets of the same, being neatly trussed in a stack of the same conical shape, are let into this cavity. The whole is then covered with turf, to prevent the volatile parts from being dissipated, which, by means of a heavy wooden mallet and a wooden stamper worked separately by two men, is beaten down and rendered as firm as possible above the wood. The stack of billets is then kindled, and a slow combustion of the fir takes place, without flame, as in making charcoal. During this combustion, the tar exudes; and a cast-iron pan being at the bottom of the funnel, with a spout which projects through the side of the bank, barrels are placed beneath this spout to collect the fluid as it comes away. As fast as the barrels are filled they are bunged and made ready for exportation. From this description it will be evident that the mode of obtaining tar is by a kind of distillation,

per descensum: the turpentine melted by the fire, mixing with the sap and juices of the fir, while the wood itself becoming charred, is converted into charcoal."

This method of making tar was practised by the ancient Greeks, and is described by Theophrastes and Dioscorides. Dr. Clarke remarks that "there is not the smallest difference between the tar-work in the forests of Westro-Bothnia and those of ancient Greece. The Greeks made stacks of pine, and having covered them with turf, they were suffered to burn in the same smothered manner; while the tar melting, fell to the bottom of the stack, and ran out by a small channel cut for the purpose."

A more recent observer, Mr. Laing,[1] states that those "fir-trees which are stunted, or from situation not adapted to the saw-mill, are pealed of the bark a fathom or two up the stem. This is done by degrees, so that the tree should not decay, and dry up at once, but for 5 or 6 years should remain in a vegetative state, alive but not growing. The sap thus checked makes the wood richer in tar; and at the end of 6 years, the tree is cut down, and is found converted almost entirely into the substance from which tar is distilled. The roots, rotten stubs, and scorched trunks of the trees felled in clearing land, are all used for making tar. In the burning or distilling, the state of the weather, rain, or wind, in packing the kiln, will make a difference of 15 or 20 per cent. in the produce of tar. The barrels containing tar are always very thick and strong, because on the way to market, they have often to be committed to the stream to carry them down the rapids and waterfalls. The price is only 6*s.* 8*d.* sterling to the peasant, and often not so much. Those who follow tar making are always the most indigent."

TUTENAG, an alloy of 8 parts copper, 3 of nickel, and 6½ of zinc. It is a very hard, fusible alloy, not easily rolled, and is best adapted for casting. It sometimes contains a small proportion of iron.

TYPE. See PRINTING, Sect. II.

ULTRAMARINE, a beautiful blue pigment, so called because it is said to have been brought from *beyond the sea*, from the island of Cyprus, or because it is bluer than the sea. It is obtained by isolating the colouring matter of *lapis lazuli*, or *lazulite*, a mineral of indeterminate composition, as will be seen from the following analyses, the first of which is by Gmelin, and the second is quoted by Dana:—

Silica	49		45·5
Sulphuric acid	2		5·9
Alumina	11		31·8
Soda	8		9·1
Lime	16		3·5
Magnesia	2	Chlorine	0·4
Peroxide of iron	4	Iron	0·8
Sulphur	a trace		0·9
Water	a trace		0·1
	92		98·0

Lazulite is found chiefly in granular limestone, near granite, as on the shore of Lake Baikal. It is mostly brought from China, Thibet, and especially from Badakschan, in Tartary. It often contains scales of mica and iron pyrites. It is found in masses more or less pure, generally in small volume, fragile, but capable of scratching glass, of granular texture, imperfectly laminated, and almost transparent at its edges. It crystallizes in dodecahedrons with rhombic faces, but the crystals are rare. Its density is 2·5 to 2·96. The colour which occurs in isolated spots passes from celestial blue to pure blue and indigo purple. It is usually disseminated in a rock which contains many other laminated substances, among which a *white lazulite* has been named.[2] The iron pyrites sometimes disseminated in lazulite are of a golden yellow colour, and help to relieve the lustre of the blue; these pyrites have been mistaken for pellets of gold. The mineral is known in commerce as *lapis*, more or less rich in *lazulite;* it sometimes contains only one-third or one-fourth of the valuable mineral. The finest specimens of lazulite are reserved for jewellery, and for Florentine mosaic. The less rich specimens are used for decorating apartments. The walls of the palace of Orloff, at Petersburg, are said to be covered entirely with lazulite of Great Bokhara. The ancients worked in this stone: many antique engravings, hollow or in relief, are extant; but the ancients do not seem to have known the art of separating the ultramarine which constitutes the chief value of lazulite. Before the blow-pipe, lazulite loses its colour, and changes first into a grey enamel, and thence into a white. In hydrochloric acid lazulite speedily loses its colour, and forms a gelatinous solution with the evolution of sulphuretted hydrogen.

Not more than from 2 to 3 per cent. of the finest ultramarine can be separated from the best lazulite. The method of doing this is so very tedious, and the destruction of lazulite so large, that the cost to the artist of ultramarine may be as much as 20 guineas per ounce.[3] In order to separate the colouring matter the lazulite is first ground with water on a hard stone of fine grain, and the powder thus produced being dried by exposure to the air, is kneaded up into a dough with a resinous composition called *pastello*, composed of linseed-oil, wax, and resin or pitch, and the mixture is left to consolidate during 8 or 10 days. The dough is then washed in warm water until the water begins to appear blue; this is done 3 times, each water being kept separate. From each of the coloured waters ultramarine subsides in a powder, which is different in each case in beauty and brilliancy of colour.

Another method is to raise the lazulite to a red heat, and then to quench it in strong wine-vinegar: the vinegar is next to be poured off, the stone dried and pounded. The powder thus produced is to be ground on a stone with a muller and water until it is quite impalpable. It is to be dried in the sun or in

(1) Tour in Sweden in 1838.

(2) In the Musée Minéralogique, at Paris, are two crystals of lazulite, in which may be seen the transition from the blue to the white variety.

(3) Messrs. Newman of Soho Square have allowed us to examine their stock of genuine ultramarines, some of which have been sold at this price.

a warm room, and made up into a dough with a mixture of linseed-oil and strong brandy. The dough is to be rolled out into a cake, spread upon a clean broad plate, and covered with paper smeared with linseed oil to keep off dust: in this state it is to be left in a damp place, such as a cellar, for 4 days. The plate with the dough is next to be placed in a sloping position in a basin of glazed ware, capable of holding 8 or 9 quarts of water. The plate being held in the left hand in the sloping position, a stream of clear water is to be allowed to fall upon the dough, while it is being worked up with a spatula held in the right hand of the operator; in this way the ultramarine becomes loosened, and flows away with the water. When the basin is half full, another basin is selected, and the operation proceeded with. A third and a fourth basin are also used, and in this way four different kinds of ultramarine are obtained, that in the first basin being the finest. The dough is then again kneaded, and returned to the cellar for 8 days. In the meantime the basins are covered up to keep out dust, and in the course of 24 hours the colour is deposited. The water is gently decanted off into other basins so as not to disturb the deposit. Each deposit is washed 5 or 6 times with clean water in order to detach portions of oily or resinous matter which came over with the colour: these are picked out separately, or they are burnt away by raising the precipitate to a red heat: the ultramarine, on cooling, regains its beautiful blue colour, but the quality suffers somewhat in this process, and it requires a diligent porphyrisation to restore it to its first quality. All the waters used for washing the precipitates are set apart, and are afterwards treated for different kinds of inferior ultramarine. The original cake having been left in the cellar for 8 days, is again put into the bowl as before; warm, but not boiling water, is poured over it, and it is washed or kneaded by hand instead of with the spatula. When the water becomes coloured it is poured into another bowl, and the process is repeated so long as the water is coloured. The precipitates at the bottom of these bowls are washed 3 times, dried, and extraneous matters picked out. Lastly, the cake, or the remaining dregs of it, is washed with warm lye, when a bluish grey precipitate is produced, which, when washed, dried, and picked, forms what is called *ultramarine ash.*

Ultramarine is estimated by its brilliant colour and impalpable state of comminution. The former quality depends, to a great extent, upon the latter, and this can only be secured by thoroughly grinding the lazulite. The state of comminution is judged of by taking some of the ultramarine into the mouth. If it feel sandy, and grate between the teeth, its quality is not good; but if it behave like flour or well-bolted meal, it is of good quality, provided, of course, that the colour be brilliant. The best test of its being genuine is to heat it to redness; if its colour does not change it has been prepared from oriental lazulite: if it becomes green in the fire it is of inferior quality, and has been prepared from occidental lazulite. The colour known as *azure-blue* is prepared from the latter, but it changes to green in the course of time, as may be noticed in those pictures of the old masters in which genuine ultramarine has not been used.

Such is the apparently complicated process for obtaining genuine ultramarine. It has probably been practised from the 14th century, and was not of course founded upon any chemical analysis of lazulite; yet how completely it answers the purpose intended! It was first remarked by Clément and Désormes,[1] that the waters employed in separating the ultramarine from the pastello were soft and unctuous to the touch like weak alkaline leys; and they actually obtained an alkaline residue on evaporating these waters. Hence the theory of the process is simple. It appears to be based on this circumstance, that the oil of the pastello unites with the ultramarine of the lazulite (which we have seen contains soda), and forms a kind of soap therewith which is readily soluble in tepid water; while the gangue or stony portions of the lazulite, not containing soda, do not form any such soap, but remain entangled with the insoluble wax and resin of the pastello on which water has no sort of action. A more simple and beautiful contrivance for separating the minute portions of ultramarine from lazulite can scarcely be imagined.

The specific gravity of ultramarine is 2·360, water being 1·000. If the mastic has not been entirely removed, ultramarine can be fused at a very high temperature into a black enamel; but, if quite pure, the ultramarine forms an almost colourless glass. Heated with borax, it readily forms a very transparent glass; it disengages sulphur and a little carbonic acid, the quantity of which varies with the quality of the ultramarine. Ultramarine is decomposed by dilute sulphuric and hydrochloric acids, sulphuretted hydrogen being given off. When nitric acid is added to ultramarine both are decomposed, and red fumes of nitrous acid appear. In this way ultramarine can be readily distinguished from smalt. [See Cobalt.] Acetic acid acts more feebly. Hydrogen gas passed over ignited ultramarine colours it light-red from the formation of liver of sulphur, sulphuretted hydrogen and water being evolved. By passing oxygen gas over it at a red heat the colour is changed to green. When solutions of potash or soda are heated with ultramarine, alumina is abstracted therefrom, but the colour is not altered; but caustic potash, heated with ultramarine, destroys its colour, and a reddish mass remains. Ammonia has no action.

The high price of ultramarine, and the unexampled effects which it produces in painting, rendered it very desirable to produce this substance artificially. Several of the most illustrious French chemists made the attempt at the commencement of the present century. They were for some time baffled by the discordant results obtained by analysis, and were unable to distinguish which of the ingredients of ultramarine were essential, and which accidental or superfluous. Thus, in a paper read before the National Institute in 1800, by the citizen Guyton, the opinions of other

(1) "Annales de Chimie," 1806.

chemists are referred to. Before the analysis by Margraf the colour of ultramarine had been attributed to the presence of copper; but that chemist found only silica, sulphate of lime, lime, and a little iron, present. Others suspected the presence of oxide of cobalt: others, again, fluoric acid. Klaproth's analysis gave silica 46 per cent., carbonate of lime 28, alumina 14·5, sulphate of lime 6·5, oxide of iron 3, and water 2. Guyton thought that the colouring matter was a blue sulphuret of iron, and that ultramarine might be produced artificially by combining sulphuret of iron with certain earths.

In 1806, Clément and Désormes published an analysis of ultramarine: they admit the difficulty of the analysis of this substance, but are disposed to regard it as being composed of silica 35·8 per cent., alumina 34·8, soda 23·2, sulphur 3·1, and carbonate of lime 3·1.

The first step towards the production of artificial ultramarine was made in 1814, when Vauquelin, in visiting the plate-glass manufactory of St. Gobain, was informed by M. Tassaërt (the director of the sulphuric acid and soda department of that establishment), that in taking down the soda furnaces a blue substance was found, when grit-stone (grès) was used in the construction of the sole, but that there was no such deposit when the sole was of brick. The substance in question was similar to lapis lazuli. On reducing it to powder, and washing it, Vauquelin found that it was discoloured by the mineral acids with the disengagement of sulphuretted hydrogen; that it was not attacked by boiling alkaline solutions, nor destroyed at a red heat. Vauquelin states, that although the composition of this artificial product is unlike that of lapis lazuli, yet he is not without a hope that this circumstance may lead to the production of ultramarine artificially.

This observation, and the suggestion founded upon it, appear to have been forgotten for nearly 14 years. In March, 1828, Gmelin of Tubingen published in the *Hesperus*, No. 76, an analysis (which we have already quoted) of lapis lazuli from St. Petersburg, and of ultramarine from the best makers in Paris, and also a sample from Professor Carpi of Rome. This was found to contain soda 12·06 per cent., lime 1·55, alumina 22, silica 47·31, sulphuric acid 4·68, sulphur 0·19, water, resin, &c. 12·21. Gmelin states that the analysis by Clément and Désormes is calculated to lead to error: he suggests that sulphur is the colouring material of ultramarine, and after referring to Tassaërt's observation, states that he had succeeded in producing ultramarine artificially, but that the honour and profit of the discovery were lost to him in consequence of his having been so indiscreet as to inform Gay Lussac and other chemists in Paris in the previous year (1827), that he was engaged in the attempt to produce this pigment by artificial means. On the 4th Feb. 1828, Gay Lussac announced to the Academy of Sciences at Paris, that M. Guimet had succeeded in making ultramarine, but that at present he wished to keep his process secret. Gmelin infers that this announcement would not have been made had it not been for the hint which he gave to Gay Lussac. He then proceeds to justify his claim to the discovery by publishing his process. Hydrate of silica and alumina are prepared, the first by fusing well-pulverized quartz with 4 times its weight of carbonate of potash; the fused mass is to be dissolved in water, and the silica precipitated by means of hydrochloric acid. The alumina is prepared by precipitating a solution of a pure salt of alumina by means of ammonia. The two earths are to be carefully washed with boiling water, and the quantity of pure earth is to be determined after heating to redness a certain quantity of the moist precipitate. The hydrate of silica employed contained, in 100 parts, 56 of anhydrous silica, and the hydrate of alumina 3·24 parts. Dissolve with heat, in a solution of caustic soda, as much of this hydrate of silica as it can dissolve, and determine the quantity of earth dissolved. For 72 parts of this anhydrous silicate take such a quantity of hydrate of alumina as contains 70 parts of dry alumina. Add it to the solution of the silica and evaporate, stirring it constantly, until a moist powder only remain. This compound of silica, alumina, and soda, forms the base of ultramarine, and it is to be coloured by the addition of sulphuret of sodium; for which purpose a mixture of 2 parts sulphur and 1 part anhydrous carbonate of soda are to be gradually heated in a Hessian crucible with a well-fitting cover, until the mass is well fused. This sulphuret is to be projected, in very small quantities at a time, into the fused compound of silica, alumina, and soda. As soon as effervescence ceases, another portion of the sulphuret is to be added. The crucible containing the preparation is to be kept at a moderate red heat for one hour, and is then to be removed from the fire and allowed to cool. It consists of ultramarine, with an excess of the sulphuret which is to be removed by the action of water. If sulphur now be in excess it may be expelled by the application of a moderate heat. If the mass of ultramarine be not equally coloured throughout, the finest parts may be separated, and reduced to a very fine powder by washing with water.

A translation of this paper in the *Hesperus* from German into French was made by Liebig, and forwarded to Gay Lussac, who, in one of the parts of the Annales de Chimie et de Physique for 1828, admitted that Gmelin did inform him that he believed it possible to make ultramarine artificially, but that he, Gay Lussac, was not aware that any one in Paris was engaged in the attempt to form it; that Guimet's experiments were conducted at Toulouse, and that Gay Lussac only knew of them in consequence of having received a specimen of ultramarine from Guimet 6 weeks before, and that he had announced the important discovery to the Institute. As to the priority of the idea, no one could seriously think of appropriating that, after Tassaërt's observation; but that if the question of priority were raised, then it must be claimed by the "Société d'Encouragement,' &c. of Paris, who, 4 years before, had offered a prize of 6,000 francs for the manufacture of artificial ultra-

marine,[1] a sufficient proof that the Society thought its artificial production possible. Gay Lussac adds a note from Guimet, who states that at the time when Gmelin made his indiscreet communication at Paris in the spring of 1827, he, Guimet, had, a year before, produced artificial ultramarine at Toulouse, that he had been long occupied in the attempt to make his process economical and applicable to the Arts. In July, 1827, his blue was in the hands of several distinguished artists, one of whom he names, who spoke of it in the highest terms. Guimet defends the analysis of Clément and Désormes, and states that they found 3 parts of sulphur in 92 in all the specimens which they examined. He admits that Gmelin's recipe for the production of artificial ultramarine may be of importance to science, but not to the useful arts, on account of its costliness and tediousness.

It will be observed that, in Gmelin's process, extreme care is taken to insure the purity of the ingredients. This does not appear to be necessary. Indeed, we have been informed, that one chemist, in repeating Gmelin's process, failed, and had actually abandoned the experiment, when one of his assistants tried the effect of stirring the contents of the crucible at a low heat: he used for the purpose an iron rod, and was surprised to see the green powder change into a beautiful blue. This was attributed to the introduction into the composition of a small portion of iron from the stirrer, and some authorities maintain that, from 0·9 to 1 per cent. of iron is necessary to the production of the colour.

In 1830 we find another notice of the accidental formation of artificial ultramarine. M. Kuhlmann states, in the Annales de Chimie, &c., vol. xl., that in repairing a reverberatory furnace used for calcining sulphate of soda in the manufacture of soda from common salt, the brick fire-bridge was found to be covered in several places with a deposit of ultramarine. It appears that, previous to the formation of this deposit, sulphuret of sodium, in small brilliant crystals of a brownish red colour, had been formed. M. Kuhlmann attributes the formation of the ultramarine to the action of the soda and sulphuret of sodium on the silica and alumina of the bricks.

In May, 1831, Guimet addressed Gay Lussac, and reported the progress of his valuable discovery. He refers to the importance to the arts of being able to supply ultramarine of good quality at a low price, as it is so eminently calculated to take the place of cobalt-blue in painting, and of oxide of cobalt or smalt in colouring glass. Enormous quantities of this colour were used for colouring paper, woven fabrics, and other manufactures, at a price varying from 2·75 to 3 francs per lb. There was no doubt that the artist would prefer artificial ultramarine to cobalt-blue, but for common purposes it seemed scarcely possible to manufacture ultramarine at a cost sufficiently low. Montgolfier, the celebrated paper-maker, found that 1lb. of artificial ultramarine produced the effect of 10lbs. of the finest smalt, and produced a more uniform tint. The price first charged by Guimet for common ultramarine, was 20 francs per lb., which, after 9 months' demand for the article, he was enabled to reduce to 16 francs. The first quality for artists was charged 60 francs per lb., and a second quality 20 francs. As Lyons was likely to use a good deal of the ultramarine, Guimet established his factory three leagues from that city, and expressed his hope that France would soon be independent of Germany for the supply of blues except cobalt blues for the purposes of pottery and porcelain.

We are not aware that Guimet has ever published his process. Previous to the year 1847 there was only one manufactory in France in addition to Guimet's, viz. that of Courtial. In Germany, Leverkus was known as a maker. In that year Zuber & Co. of Rixheim, in France, commenced operations, and after this a number of manufactories, twenty at least, were established in some of the small towns on the banks of the Rhine and elsewhere, and many processes for the manufacture were published: Gmelin published an improvement on his first process: Persoz of Strasburg, and Köttig, director of the Saxon Ultramarine Works, have also given processes. We will give one or two that have been published. The reader who desires more, will find them in the works mentioned below.[2]

Kressler states that a mixture of 1 part of clay, perfectly free from iron, with 1 part of sulphur and 2 parts of anhydrous carbonate of soda, yields a yellowish mass when ignited; but, that if a trace of sulphate of iron be added to the mixture, a mass is obtained which is black, green, or blue, according to the degree of heat to which it has been subjected. Gmelin states, that when potash is used, instead of soda, the blue colour is not obtained.

Professor Brunner, in repeating Gmelin's process, always obtained a product very inferior to the natural product; but at length he obtained a satisfactory result by using a peculiar sand found near Longnau in the canton of Berne, containing 94·25 per cent. of silica, 3·03 of alumina, 1·61 of lime, and 0·94 of sesquioxide of iron. An intimate mixture is made with 70 parts of this sand, washed, 240 parts of burnt alum, 48 parts of powdered charcoal, 144 of flour of sulphur, and 240 of anhydrous carbonate of soda, all reduced to an impalpable powder. The mixture is introduced into a Hessian crucible, and the cover luted down. The crucible is then exposed to a moderate red heat kept as steady as possible for an hour and a half, after which it is suffered to cool. If the operation has been successful, the mass presents a loose, semifused appearance, and a greenish or reddish-yellow liver of sulphur colour; it is also reduced to about $\frac{2}{3}$ths of its former volume. (If it appears solid, fused, browner in colour, and of still smaller bulk, the temperature will have been raised too high.) The mass, which is readily detached from the crucible, is put into a dish and washed with either hot or cold water,

(1) This prize was awarded to Guimet in 1828, on which occasion he communicated his process confidentially to Gay Lussac.

(2) Gmelin, "Hand Book of Chemistry," vol. iii.; Cavendish Society's Translation, 1849. "Pharmaceutical Journal," vols. ii. vi. "Chemical Gazette," vols. i. ii. iii.

until the liquid has no longer a sulphurous taste. The residual dark-greenish blue powder is then thrown on a filter and dried. The dry powder is next mixed with an equal weight of sulphur and $1\frac{1}{2}$ times its weight of anhydrous carbonate of soda, and treated as before. The resulting mass, after washing and drying, is once more heated with the same proportions of sulphur and carbonate of soda, the product boiled for some time with water, and then thrown on a filter and washed with cold water until the liquid which passes through ceases to colour acetate of lead. The powder, after being dried, is passed through a fine sieve to separate impurities, and then treated as follows:—A cast-iron plate, or platinum dish, is covered with a layer of pure sulphur, about a line in depth, and on this about the same quantity, or a little more, of the perfectly dry compound is sifted. The plate is then carefully heated until the sulphur takes fire, the compound itself being kept from ignition as much as possible, (or the preparation may be mixed with half its weight of sulphur, and cautiously heated as before.) This process is repeated 3 or 4 times, the residue on each occasion being detached from the plate and reduced to powder. The operation is repeated until a satisfactory colour is obtained.

Brunner is of opinion that the presence of lime is of little importance in the preparation of ultramarine, and that iron is not important; that the blue colour depends on the soda, for if the above process be carried out with potash instead of soda, an analogous compound is produced, but it is perfectly white. If the burning process with sulphur be continued after the compound has attained its finest colour, a point is reached at which it ceases to increase in weight; but if it be then heated without the addition of sulphur, an increase of weight is again observed, and a mass obtained having a paler blue colour with a tinge of black, resembling that of some varieties of native ultramarine. The powder, at the same time, loses its soft, loose texture, and becomes denser and granular, in which state it does not evolve sulphuretted hydrogen with hydrochloric acid, showing that it contains no unoxidized metallic sulphuret.

In the Great Exhibition, M. Guimet appeared as the most successful manufacturer of artificial ultramarine, "his product being remarkable for the intensity of its hue, and standing well the dilution with a white powder, which is a most trying test of that property. It appeared to the Jury, assisted in the department of colours by Mr. Linton, who, as an artist, has made the chemical properties of colours a peculiar study, that for use in oil and water-colour painting, a pure blue ultramarine, unmixed with red, is desired; while, on the other hand, the ultramarine is recommended by its purple bloom as a colour upon cloth. The specimens exhibited generally possessed the latter character, and were no doubt chiefly intended for calico-printing. The discovery of a method of attaching this insoluble pigment to cloth by means of albumen, which is ultimately coagulated by heat, combined with the low cost of production, has led to a great demand for ultramarine and rapid extension of the manufacture within the last few years. Certainly, many of the finest effects in the beautiful prints, at present exhibited, are produced by its means."[1]

The quantity of ultramarine produced in France in 1848, in three manufactories, is estimated at from 90,000 to 100,000 kilogrammes; and for 1851, in four manufactories, from 150,000 to 170,000 kilogs.; the price of the finer sorts having fallen during the same period from 9 to 5·50 francs per kilog. A *green* ultramarine has been introduced for printing on cotton and paper, and it has the advantage over arsenical greens in not being poisonous nor alterable by alkalies.

The different varieties and shades of colour of artificial ultramarine are very numerous. The Rheinische Ultramarine Factory of Wermelskirchen exhibited no less than 60 distinct varieties, each of which had its own peculiar mark or brand, as follows:—

1. O_2BSF	16. O_2A	31. 3B	46. 3E
2. $O_2$1SF	17. 1	32. 4B	47. 1R
3. O_1BSF	18. OSF	33. 5B	48. 2E
4. O_2SF	19. 1OSF	34. 3	49. A
5. O_1SF	20. 2OSF	35. 4	50. E
6. O_2ASF	21. D1B	36. 5	51. BA
7. 1SG	22. 2SC	37. 7	52. D
8. SF	23. 3SF	38. O_1A	53. 1B
9. 1F	24. O	39. O_3A	54. F
10. FS	25. 1O	40. O_4A	55. 2
11. 2FS	26. 2O	41. DR	56. 5N
12. O_2O	27. 3O	42. 1DR	57. 3A
13. O_{21}	28. O_1B	43. 4E	58. 6M
14 O_2B	29. OOB	44. 2DR	59. 4A
15. O_2	30. O_1	45. R	60. 7N

UMBER, an ore of iron and manganese, said to consist of oxide of iron 48 per cent., oxide of manganese 20, silica 13, alumina 5, and water 14. It is found in beds with brown jasper in the Island of Cyprus. It occurs massive and amorphous: its structure is earthy, its fracture conchoidal; it is soft and opaque; its colour is blackish, reddish, or yellowish brown; it adheres to the tongue, and falls to pieces in water: its density is 2·206. It is used as a brown pigment, and is also employed to make varnishes dry quickly.

UNIVERSAL JOINT. See COUPLINGS, Fig. 676.

URANIUM, U.60., a scarce metal, found chiefly in *pechblende*, which is an impure oxide, and also in combination with phosphoric acid in *uranitic mica*. A native oxide and a sulphate also occur, but rarely. The metal can only be obtained by means of potassium, as in the preparation of *magnesium*, which see. It is a black coherent powder, or a white malleable metal, according to the state of aggregation. The *protoxide*, UO., is a brown powder, but sometimes crystalline: it forms with acids a series of green salts. The *deutoxide* or *black oxide*, U_4O_5, does not form salts. The *peroxide*, U_2O_3, is the most important; it forms a number of yellow salts of great beauty. This oxide is used to impart a delicate yellow and a greenish yellow colour to glass. The green oxide, U_3O_4, or the deutoxide, is used to produce a black on the Berlin porcelain ware. Some of the salts of this metal would probably afford pigments, and be useful in calico-printing, if the metal were more abundant.

(1) Jury Report, Class II.

VALERIAN, a plant belonging to the genus *Valeriana*, the type of the natural order *Valerianaceæ*, of which the species *V. officinalis*, the *officinal*, or *great wild Valerian*, is used in medicine, the root, or, more properly, the rhizoma, with its root fibres, of the variety *sylvestris*, being the part employed. The root has a peculiar odour, which is due to a volatile oil, which passes over on distilling the root with water. The oil is a hydrocarbon, containing $C_{10}H_8$. Cats and rats are remarkably fond of it, and it is employed by rat-catchers as a decoy. This oil is convertible into *valeric*, or *velerianic acid*, which has been detected in a variety of products, and is one of the few organic substances which can be produced artificially. This acid forms, with bases, a class of anhydrous salts termed *valerates:* they have a sweetish taste; some may be obtained crystallized; others are amorphous.

VALONIA. See LEATHER, Section II.

VALVE. See STEAM-ENGINE—AIR-PUMP—PUMP, &c.

VANADIUM, V.68, a rare metal, discovered by Seftström in 1830 in one of the Swedish iron ores, and named after *Vanadis*, a Scandinavian deity. It also occurs in the mineral *vanadiate of lead.* Vanadium is a white brittle substance, very infusible, not oxidised by air or water, nor acted on by sulphuric, hydrochloric, or hydrofluoric acid. It is dissolved by aqua regia, and forms a solution of a deep blue colour. There is a *protoxide*, VO, a *binoxide*, VO_2, which forms with acids a series of blue salts, which tend to become green, and then red, by the production of *Vanadic acid*, VO_3. This acid unites with bases forming a series of red or yellow salts.

VANILLA, the fruit of a genus of plants, the type of the natural order *Vanillaceæ*, much used on the continent of Europe for flavouring cakes, sweetmeats, liqueurs, ices, chocolate, &c. When the Spaniards discovered America, they found that the Indians were accustomed to flavour their chocolate with this substance, the name of which is said to be derived from *vaynilla*, a diminutive of *vayna*, the Spanish for a knife or scissor-case, the fruit being long and cylindrical like the sheath of a knife. Vanilla has a balsamic odour, and a warm, agreeable flavour, which properties are due to a volatile oil and the presence of benzoic acid. When the fresh fruit is opened it is found to contain a black, oily, balsamic liquid, in which a large number of granules are floating. The fruit is prepared for the market by drying. The finest kinds of vanilla of commerce are imported from Vera Cruz, the plant being cultivated about 24 leagues north-west of this port at a place called Misantla in Venezuela. The mode of cultivation is described in "Buchner's Repertorium" (Band xlv.), from which we obtain the following particulars:—Vanilla requires a damp but warm climate, and a good soil. Hence a ground with low shrubs which give little shade is best adapted. The ground need not be tilled, but on the approach of the rainy season, slips of vanilla are planted at the root of a tree or shrub, and as the plants grow they creep up around the trunk. Once a year the plantation is cleared of the exuberant shrubs, and in the third year the plants bear fruit. At Misantla five sorts are distinguished:—1. *La Corrienté*, of which there are two kinds; one with a delicate fine skin, rich in seeds and pulp, and the other of an inferior quality, with a thick skin; the *lec, ley*, or *leg*, of some parts of South America, and the genuine vanilla of commerce. 2. *La sylvestré Cimarrone*, or *Simarona*, wild vanilla; the fruit is smaller than No. 1; it grows in the shade or among the shrubs, so that its fruit is less developed than the cultivated vanilla, with which it is identical. 3. *Mestiza:* the unripe fruit is green with brown spots; it is more cylindrical than the genuine, and easily dehiscing or bursting open on becoming dry. 4. *La Puerca:* fruit smaller than the first, and in the unripe state dark green: when drying it evolves an offensive smell, from which it is also called *hog vanilla* (*Vanille de cochon*). 5. *La Pompona.* The fruit is shorter and thicker than No. 1, and has a very delicate epidermis. The smell is pleasant, and is very evident when becoming dry, but is not so agreeable as No. 1: it loses its smell in time, and hence is but little valued. It is known in France under the name of *Vanillon.*

The harvest begins about December: the yellowish green colour of the fruit, which was formerly green, indicates its ripeness. The fruit, however, is sometimes gathered before it is ripe. The pedunculus is always left on the fruit, and when, by drying, the pedunculus has lost its green colour, the dressing commences; for which purpose straw mats, covered with woollen blankets, are spread on the ground, and when heated by the sun the fruit is distributed over them; and this, when warmed, is folded up in the blankets, placed in boxes covered with cloths, and further exposed to the sun. Within 12 hours the fruit should have assumed a coffee-brown colour: if not, the process is repeated next day. In unfavourable weather artificial heat is employed. The vanilla is improved by daily exposure to the sun on mats for about 2 months. The cultivator knows by experience when the fruit is properly dry; if dried beyond a certain point, there is loss both in weight and quality. When the dressing is complete the fruit is tied up in bundles of 50 pods each, and packed in tin boxes. Inferior sorts, such as Nos. 4 and 5, are sometimes placed in the middle instead of the genuine sorts, of which 5 kinds are distinguished; viz. *primiera*, which must be 24 centimes long, and proportionally thick, and filled with pulp to the pedunculus; *chica fina*, which is shorter than the foregoing, so that 2 fruits are counted for 1; *sacate*, which is less thick than the first, and at the base not quite filled with pulp; *resacate*, which is small and dry, 4 being reckoned for 1: (these fruits were gathered before they were ripe); and *basura*, the most inferior sort, the fruit of which is very small, spotted, and cut or broken. According to another authority, the fruit is first allowed to ferment for 2 or 3 days, then exposed to the sun, and when about half dry, rubbed over with the oil of palma Christi or the oil of cocoa. It is again exposed to the sun, and oiled a second time.

The fragrant vanilla, *V. planifolia*, was introduced

by the Duke of Marlborough into Great Britain in 1800, whence it found its way to the gardens of the Continent, and from Holland it was sent to Japan, where it is now much cultivated: but as this plant rarely flowered, and never produced fruit in Europe, it was not supposed that it was capable of yielding the vanilla of commerce. Professor Morren of Brussels, however, has shown,[1] that it is possible to produce in hot-houses in Europe vanilla equal or superior in quality to that from Mexico. The species cultivated by him was also *V. planifolia*, and he has shown that it seldom flowers in Europe on account of its not being allowed to grow in lofty humid hot-houses. The plants should not be under 5 or 6 years of age: they should be shaded, and supplied with heat and moisture. The best soil is coke placed over small pieces of birch or poplar wood. The plants should be allowed to creep up an iron frame or other support: the branches should be twined, and their extremities cut and burned with a hot iron to stop the flow of the sap and stimulate the flowers. Under these favourable circumstances, the plant flowers in Liege from February to April, and when it bears fruit it requires a year and a day to ripen. If the plants do not bear fruit they flower again the next year, but if they bear fruit they require some years' rest before they blossom again. There is a curious reason why the vanilla does not produce fruit in Europe when it has flowered, arising from the structure of the flower itself, "which has this peculiarity, that the retinaculum is highly developed, so that this organ forms a curtain suspended before and above the stigmatic surface, thus separating it completely from the anther, which in its turn incloses in two cavities, naturally short, the pulverulent masses of pollen. From this structure it results that all approximation of the sexes in orchideous plants is naturally impossible. It is thus necessary either to raise the velamen or to cut it, when the plant is to be fecundated, and to place in direct contact the pollen and the stigmatic surface. The fecundation never fails, and we may be convinced of its success by observing the flower some hours after the operation. If impregnation has been effected, the sepals and petals reverse inwardly, and the flower droops instead of remaining erect. So soon as the following day the ovarium elongates." The process, which is thus required to be performed artificially in Europe, is done naturally, by means of insects, in countries where the plants grow.

Vanilla acts as a slight stimulant, and it is a valuable addition to several articles of food in cases where there is want of energy and activity in the system.

VAPOUR. See STEAM—EBULLITION.

VARNISH. A varnish is a solution of a resin or of a gum-resin in a liquid, which, being spread over a surface, evaporates, and leaves the solid in the form of a brilliant, transparent film. The principal substances used in varnishes are the following:—

SOLVENTS.	SOLIDS.		COLOURS.	
Oil of Nuts.	Amber.	Elemi.	Gamboge.	Annotto.
,, Linseed.	Animè.		Dragon's blood.	Red Saunders.
,, Turpentine.	Copal.	Benzoin.	Aloes.	Cochineal.
,, Rosemary.	Lac.	Colophony.	Saffron.	Indigo.
Alcohol. Ether.	Sandarach.	Arcanson.	Turmeric.	
Wood naphtha or pyroligneous ether.	Mastic.			
	Damar.			
	Common resin.			

The resins, or as the varnish-maker calls them, *gums*, may be used either singly or combined, and the same remark applies to the solvents. One of the most desirable qualities in a varnish is durability, a quality which depends greatly on the comparative insolubility of the resin employed, its hardness, toughness, and permanence of colour. *Amber* is most distinguished in these respects: it resists the action of ordinary solvents, and requires to be fused at a high temperature, for making varnish: it is hard, and moderately tough, and its colour is scarcely acted on by the air. The objections to amber are its costliness and the length of time required for amber-varnish to dry: it does not become full hard under many weeks. [See AMBER.] *Animè* is imported from the East Indies in chests weighing from 3 to 5 cwt. Those which contain the palest and largest gum fetch the highest price. It should be scraped by hand before being sold, but a good deal of it is *pickled*, that is, cleaned from its rust-like colour, by being steeped for several days in a strong alkali, well washed with a broom and then rinsed with water. This kind sells for about one-third less than that which has been scraped with a knife. The varnish-maker picks out the large, pale, transparent pieces, or they are sold separately as *body-gum;* the next best in quality is separated from the third and worst quality, which is used for gold-size or japan-black. Animè is almost as insoluble and hard as amber, but not so tough: the varnish made with it dries quickly, but is liable to crack, and the colour deepens by exposure to air and light. Animè is largely used in oil varnishes, and there is a large proportion of it in *copal varnishes* on account of its drying quickly. *Copal* is produced in India, America, the West Indies, Sierra Leone, &c. Dr. Lindley says that "the copal of Madagascar, and probably of the East Indies generally, is furnished by *Hymenæa verrucosa*," that "*Vateria Indica* furnishes the resin called in India *copal*, (in England known by the name of *gum animi*,) and very nearly approaching the true resin of that name: in its recent and fluid state it is used as a varnish, (called *Piney* varnish,) in the south of India, and, dissolved by heat, in closed vessels, is employed for the same purpose in other parts of India; it is extremely tenacious and solid, but melts at a temperature of $97\frac{1}{2}°$ Fahr. Dr. Wight tells us that the natives obtain it by the simple process of cutting a notch in a tree, sloping inwards and downwards: the resin collects there, and soon hardens."[2] Copal is

(1) Professor Morren's interesting paper was read before the British Association at Newcastle, and is inserted in the third volume of the "Annals of Natural History," 1839.

(2) "The Vegetable Kingdom," 1846. On the Malabar coast, this resin, under the name of *Piney Dammar*, is made into candles, "which diffuse in burning an agreeable fragrance, give a clear

generally imported in lumps about the size of small potatoes, of a slightly yellow tint, and often including insects and animal remains. It is often covered with a clay-like substance, from which it is freed by the dealers by scraping. The finest and palest lumps are selected for what is called *body*-gum; the next best form *carriage-gum*, and the remainder being freed from wood and stones, forms what is called *third*, or *worst quality*, and is used for gold-size or japan-black. Copal has a conchoidal fracture; it is transparent, inodorous, and tasteless. Its density varies from 1·045 to 1·139. It softens by heat without becoming viscid, and at a higher temperature fuses, partly decomposes, and gives off an aromatic odour. Copal is next in durability to amber: the pale specimens, when made into varnish, become lighter by exposure. It is an excellent material for varnishes, and attempts have been made to use it as the basis of a spirit varnish; it is, however, so little soluble in alcohol, that when boiled therein, only a small portion dissolves, and the remainder swells and softens. It is said, however, that by reducing copal to an impalpable powder, and exposing it for about 12 months to the action of the air, it becomes soluble in alcohol, and may be used for preparing varnishes. The addition of a small quantity of camphor increases the solubility of copal in alcohol; the same effect is produced by fusing it, setting it on fire, and allowing it to burn a few minutes: these, and similar plans, however, produce a very inferior varnish. Oil of rosemary is said to be one of the best solvents of copal: ether is probably the best solvent, but it evaporates so rapidly that the varnish cannot be spread equally. The oils of spruce and lavender have also been used as solvents.

The three resins, amber, animè, and copal, either separately or mixed in certain proportions, are converted into varnish by fusion and the addition of linseed-oil heated nearly to its boiling point: the combination of the resin and the oil is promoted by stirring and boiling, and the required degree of fluidity in the varnish is attained by the addition of oil of turpentine. These are the most important of the *oil varnishes;* they are the most durable, they are hard enough to bear polishing, and they possess considerable brilliancy. They are used for works of the best quality, such as are exposed to the weather or to much friction, as coaches, japan-work, and house decorations.

Lac and *sandarach* form the basis of *spirit varnishes:* these resins are more soluble than amber, animè, and copal; they are dissolved in spirit of wine, or pyroligneous spirit, which is cheaper. In France, where alcohol is very cheap and abundant, spirit varnishes are largely employed.[1] They are used for cabinet and painted works not exposed to the weather. [See LAC—SANDARACH.] Lac is harder than sandarach, and is the basis of most lackers [see LACKER], and also of French polish [see FRENCH POLISH]. Sandarach is used for making a pale varnish for light-coloured woods: it may be hardened by the addition of shell-lac or of mastic if required to be kept pale; and when required to be polished, Venice turpentine is added to give it body.

Mastic is a soft resin: dissolved in spirits of wine or oil of turpentine it makes a very pale varnish: it is brilliant, works easily, and flows better on the surface than most other varnishes. It can also be removed by friction with the hand, hence its use as a picture varnish and for other delicate works. See MASTIC.

Damar is softer than mastic: it forms an almost colourless varnish with turpentine: mixed with mastic it forms a moderately hard, flexible, and almost colourless varnish adapted for maps and similar purposes.

Common resin, dissolved with the assistance of heat in turpentine or linseed oil, makes a hard, brittle, brilliant varnish, which is employed for common purposes, as in house painting, toys, cabinet work, &c. It improves the brilliancy of other varnishes, but renders them brittle unless used sparingly.

The *linseed-oil*, used as the vehicle for the harder resins, should be pure, pale, well clarified, and combined with the resin at as low a temperature as possible. Unless these conditions be attended to, a dark varnish is produced which becomes darker by age. This oil gives softness and toughness to the resin, but produces a slowly drying varnish. It is clarified for the best varnishes by being gradually raised to near the boiling point in a copper pan, Fig. 2221. About 2 hours should be occupied in attaining this temperature: it is then skimmed and left to simmer for about 3 hours longer. About ¼ oz. of dry magnesia per gallon of oil is then gradually stirred in: the heat is kept up for another hour, and the whole is then left to cool very slowly. After this it is transferred to lead or tin cisterns, and left tranquil for about 3 months, when the magnesia combines with the impurities of the oil and subsides. The clarified oil is drawn off from above, and the lower portion is used for black paint. A pale drying oil may be prepared in this way by substituting for magnesia, 2 oz. of white copperas (sulphate of zinc), and 2 oz. of sugar of lead, to every gallon of oil. Linseed oil, converted into a drying oil by boiling and adding litharge and red-lead, is sometimes used as a cheap varnish. The linseed-oil is raised to the boiling point in about 2 hours, and after skimming, about 3 oz. each of dry litharge and red-lead per gallon of oil are slowly sprinkled in, and the whole is boiled for about 3 hours, or until little scum is formed or much smoke emitted. The varnish-maker judges whether the oil be properly boiled by

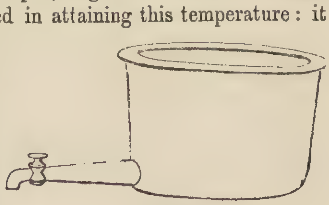


Fig. 2221.

bright light with little smoke, and consume the wick so as not to require snuffing. Some of these candles that were sent home were highly prized and sold for very high prices." (*Wight.*) Their importation was stopped by the high duties that were levied on them.

(1) Dumas, in the seventh volume of his "Traité de Chimie," has a large collection of recipes for spirit varnishes.

dipping the end of a feather into it; if it be burnt off, or curl up briskly, the boiling is sufficient. The oil is then left to cool very gradually, during which the larger portion of the driers subside. The oil is preserved in close leaden cisterns. For a pale oil the driers are white lead, sugar of lead, and white copperas.

Turpentine is in extensive use for varnishes, either as a vehicle for the resins or for thinning oil varnishes, in which case it is used hot. The turpentine should be of the best quality, clean and limpid; it is greatly improved by age, and should be kept for months or even years. Turpentine varnishes are cheap and flexible; they dry more quickly than oil varnishes, and are of a lighter colour, but not so tough or durable. Mastic, damar, and common resin may be dissolved in oil of turpentine either cold or at a gentle heat.

Alcohol or *spirits of wine* is used as the vehicle for sandarach and shell-lac, as in the *white* and *brown hard spirit varnishes.* Spirit varnishes dry more quickly, harder and more brilliant than those made with turpentine. The spirit must contain very little water or it will not dissolve the resins; and in applying the varnishes a moderately moist atmosphere is sufficient to occasion such a precipitation of the resins as to produce a dull, cloudy, or milky effect on the varnished surface: in which case the varnish is said to be *chilled.* The varnish-maker ascertains whether the spirit is strong enough by steeping a piece of writing paper in it and setting it on fire; if the flame consume the paper the spirit is judged to be sufficiently strong; if not, it contains too much water. See ALCOHOL.

Naphtha or *pyroligneous ether* is objectionable on account of its smell, but is used for cheap varnishes. It dissolves the resins more readily than ordinary spirit of wine, but the varnish is not so brilliant.

The other substances mentioned in the table at the head of this article do not require further notice in this place. Most of them are described under their respective heads. The colours are chiefly used for lackers. See LACKERS.

Considerable heat being required in the preparation of oil varnishes, and the materials employed being very inflammable, the factory should be detached from other buildings and constructed for the purpose. Directions respecting the structure of the buildings, the utensils, &c. required, and the processes adopted in the manufacture of varnishes, are given by Mr. J. Wilson Neil in his Essay contained in the 49th vol. of the "Transactions of the Society of Arts." Mr. Neil was presented with the Society's Gold Isis Medal for this Essay, to which we have been considerably indebted in the preparation of this article.

The copper used for the purposes of boiling oil, gold-size, Japan, and Brunswick black, &c., is called a *set-pot,* and is represented in Fig. 2222, with the flue winding round it. The *gum-pot,* in which the resins are fused, is set in a small furnace as shown in Fig. 2223. The gum-pot is of copper 2 feet 9 inches high and $9\frac{1}{2}$ inches diameter. The lower part *a* is raised out of one piece; the upper part *b* is of sheet copper, cylindrical, 10 inches diameter at the top and 2 feet 2 inches high, and is attached by rivets to the

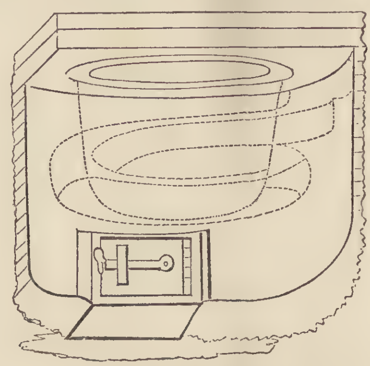


Fig. 2222. THE SET-POT.

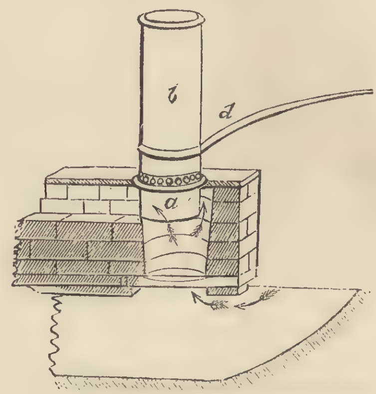


Fig. 2223. THE GUM-POT.

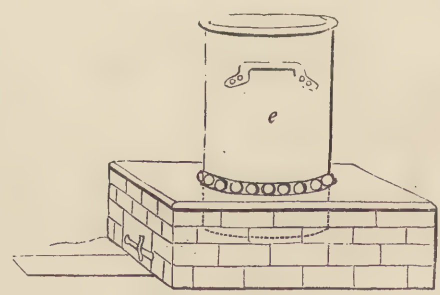


Fig. 2224. BOILING-POT.

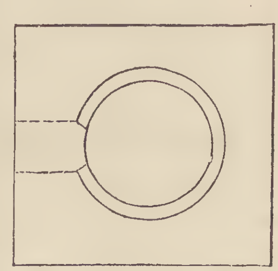


Fig. 2225. *Plan.*

lower part or bottom *a;* but before riveting, a flange of copper is fixed just below the large rivets; an iron hoop *d,* with an iron handle, is also attached to the cylinder. A copper *boiling-pot,* shown in elevation and plan, Figs. 2224, 2225, is required; the bottom, shown by the dotted lines, is raised out of the solid, and is 7 inches high and 20 inches in outside diameter: the cylinder or body of the pot is

2 feet 10 inches high, and is well riveted to the bottom, the rivets being hammered inside and out so as to project and support the pot and its contents instead of a flange. The pot is made to fit neatly into a hole in a plate of iron, Fig. 2226, which covers the top course of the brickwork. The cylinder has a strong handle on each side.

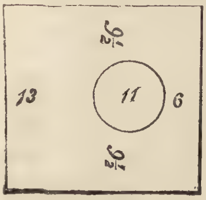


Fig. 2226.

The utensils required are ladles, stirrers, (of the form shown in Fig. 2227,) and funnels of copper; an oil-jack, Fig. 2228, of the capacity of 2 gallons, for pouring in hot or boiling oil; a brass or copper sieve, 60 meshes to the inch and 9 inches diameter, for straining the varnish; a brass sieve, 40 meshes to the inch, 9 inches diameter, for straining gold-size, turpentine, varnish, boiled oil, &c.; and a similar sieve for straining japan and Brunswick black: a saddle, Fig. 2229, or sheet of tinned iron 12 inches broad and turned up 1¼ inch; it is placed between the edges of the set-pot and the funnel to receive the drops of varnish spilled during the taking out. A pot like a watering-pot without a rose is used for pouring oil of turpentine, and there are a few other articles which do not require particular notice.


Fig. 2227.


Fig. 2228.


Fig. 2229.

For making varnish on a small scale a gum-pot similar to that shown in Fig. 2223, or smaller, may be used; also an iron tripod with a circular top into which the gum-pot will easily fit. The operation may be conducted in a hollow in a field, yard, or out-house, and a temporary fire-place be raised round the tripod with loose bricks similar to a plumber's furnace: the fuel to be preferred is coke or charcoal. When the fire burns with a strong heat, set on the gum-pot with 3 lbs. of copal in it. The fire should not rise higher outside the pot than the depth of melted copal, or the resin is likely to catch fire. As soon as the copal begins to fuse it should be constantly moved about and divided with the copper stirrer; if it feels lumpy and rises to the middle of the pot, it must be lifted off the fire, placed upon a bed of ashes[1] by the side, and kept stirring until the swelling subsides. The gum-pot is again put on the fire and stirred until the resin has become as fluid as oil, which is ascertained by lifting up the stirrer so far as to see the blade. Then call out to an assistant, "Be ready!" and he then lifts up the jack, Fig. 2228, full of clarified oil, and rests the spout on the edge of the gum-pot. When the gum rises to within 5 inches of the pot-mouth, call out "Pour!" when the oil is to be poured in very slowly, the maker continuing the stirring. In 8 or 10 minutes with a strong fire the oil and the resin will have combined into a clear varnish; this is to be ascertained by lifting up the stirrer and dropping a little of the varnish from it upon a piece of broken glass; if it be clear and transparent the combination has been effected; but the varnish must be boiled until a drop pinched between the finger and thumb will on separating them draw out into fine filaments; if not boiled enough the varnish will be soft, thick and greasy. The string-test must be tried every minute or less, and the moment it is satisfactory the pot is removed to the ash-bed and left for 15 or 20 minutes. When cold enough for *mixing*, oil of turpentine is poured out from the pouring pot in a small but gradually increasing stream; if the varnish rise rapidly in the pot, it must be constantly stirred at the surface to break the bubbles; but the stirrer must not be allowed to touch the bottom of the pot, or the turpentine will be partly converted into vapour and cause the varnish to overflow. If, however, the varnish should rise so as to become unmanageable with the stirrer, the temperature may be lowered by means of the copper ladle, a ladleful being taken out and poured back again many times. When the mixing is complete the varnish sieve is put into the copper funnel, and this into the carrying tin, and the varnish is strained; it is emptied into jars or cisterns and left for a time, the longer the better, to settle. When taken out for use the *bottoms* must not be disturbed.

(1) The ash-bed is formed by sifting dry ashes through a fine sieve; it is to be made a little larger than the bottom of the pot, 1½ inch deep and smooth and level on the surface. Instead of the ash-bed a circle of loose bricks 4 courses high may be erected to support the gum-pot.

In making varnishes on a larger scale, the boiling-pot and the gum-pot will probably have to be used at the same time. Set on the boiling-pot with 8 gallons of oil, and kindle the fire previously laid; then lay the fire in the gum furnace, and have as many 8 lb.-bags of gum weighed out as will be required: put one 8 lbs. into the pot, and kindle the fire. In about 3 minutes, with a brisk fire, the gum will begin to fuse and smoke: stir, and divide it, and attend to the rising as before. In about 20 minutes the 8 lbs. of copal will be fused into a clear liquid. By this time the oil should be brought to a simmering state as if beginning to boil; when this is the case, the maker calls out, "Bear a hand!" and the maker and his assistant lift the boiling pot by its handles out upon the ash-bed. The maker instantly returns to the gum-pot, while the assistant puts 3 copper ladlefuls of oil into the pouring jack, which he places on the iron plate at the back of the gum-pot to keep hot until wanted. When the gum is nearly fused the maker calls out, "Ready oil!" when the assistant lifts up the jack to the edge of the pot, and when the maker calls out, "Oil!" he pours it in, the boiling being continued until the mixture has become clear. The gum-pot is now set upon the stand until the assistant puts 3 more ladlefuls into the pouring-jack and 3 more into a spare tin for the third run of gum. The boiling pot will still contain 3½ gallons of oil. The gum-pot is now raised by its handle, and the edge put over the edge of the boiling pot, and its contents poured in. When the maker is ready for this pouring, the assistant stands by with a thick piece of wet carpet without

holes, large enough to cover the mouth of the boiling pot should it catch fire during the pouring, which sometimes happens when the gum-pot is very hot. Should the gum-pot fire it has only to be kept inverted and it will go out of itself; but if the boiling pot fire during the pouring, the assistant throws the piece of carpet over the blazing pot, holding it down all round the edges, and in a few minutes it will be smothered. The moment the gum-pot is emptied, half a gallon of turpentine is poured into it, and it is washed with the assistance of a broom, called a *swish*, and then emptied into a flat tin-jack: the pot is wiped dry, another 8 lbs. of gum put into it, and it is set on the furnace. This and the third run are treated like the first; when the boiling-pot will contain 8 gallons of oil and 24 lbs. of gum, a strong fire is to be kept up until a froth or scum rises and covers the surface. When it rises up to the rivets of the handles, the boiling-pot is removed from the fire to the ash-bed, and the froth stirred down. This being done, the pot is again put on the fire, and the remainder of the driers gradually introduced, always removing the pot when the froth rises to near the rivets of the handles. In about 3½ or 4 hours from the pouring in of the last gum, the boiling may be completed, but the time will vary with the weather, the quality of the oil, of the gum, the driers, and the state of the fire. About the third hour of boiling the string-test is applied: when this is satisfactory, the pot is removed to the ash-bed and the varnish stirred down until cold enough for the mixing. Five tins or 15 gallons of turpentine are gradually poured in, which will leave the varnish thick enough if the resin is of good quality and has been well run; if not of good quality, and not well fused, 12 gallons of turpentine may be too much. Therefore, after the introduction of the latter quantity, a portion of the varnish should be cooled in a saucer. It will be seen in a few minutes whether it will take more turpentine. The varnish is lastly strained and stored away. The boiling-pot, ladles, stirrers, and funnel, must be cleaned with the turpentine used in washing the gum-pot. This turpentine is first poured into the boiling-pot, and the swish is used to wash the varnish from the sides. A large piece of woollen rag is next to be dipped into pumice powder, and every part of the interior of the boiling-pot washed and polished therewith. The ladle and stirrers, &c. are similarly operated on, and rinsed in turpentine washings, and lastly in clean turpentine, and then wiped dry with a clean soft rag. The sieve is to be kept in turpentine, which will prevent it from gumming up.

The above directions mostly apply to the making of all sorts of copal varnishes. The proportions of oil, gum, &c., are subject to variation, so that a few recipes for compounding particular varnishes may be of use.

Copal varnish for fine paintings, &c.—Fuse 8 lbs. of the cleanest pale African gum-copal, and when completely run fluid, pour in 2 gallons of hot oil: let it boil until it strings strongly; and in about 15 minutes, while still very hot, pour in 3 gallons of turpentine obtained from the top of the cistern. There may be much loss of turpentine during the mixing, but the varnish will be so much the brighter, transparent, and fluid, and will work freer, dry quickly, and be very solid and durable when dry. If the varnish be too thick after being strained, hot turpentine is to be added before the varnish is quite cold.

Artist's virgin copal.—From a select parcel of scraped African gum-copal, before it is broken, pick out the very fine transparent pieces, which appear round and pale like drops of crystal; break these very small; dry them in the sun, or by a very gentle fire. When cool, bruise, or pound them into a coarse powder. Next, boil some broken bottles or flint glass in soft water and soda, and pound the glass into a coarse powder; boil it again, strain off the water, and wash it in 3 or 4 waters, that it may be perfectly free from grease, dry it before the fire, or in an oven. Mix 2 lbs. of powdered glass with 3 lbs. of powdered copal; put them into the gum-pot and fuse the gum, stirring all the time: the glass will prevent the gum from adhering together, so that a very moderate fire is sufficient to fuse the gum. When the gum is sufficiently run, pour in 3 quarts of very hot clarified oil. Let the varnish boil until it strings freely between the fingers. Mix it rather hotter than if it were body-varnish, for, as there is but a small quantity, it will be sooner cold. Pour in 5 quarts of old turpentine, strain it immediately, and pour it into an open jar or large glass bottle; expose it to the air and light, but keep it from the sun and moisture until it is of sufficient age for use.

Cabinet varnish.—Fuse 7 lbs. of very fine African gum-copal, and, when well run, pour in half a gallon of pale, clarified oil: when clear, mix it with 3 gallons of turpentine, and strain. This, if properly boiled, will dry in 10 minutes; but if boiled too strongly it will not mix with the turpentine; and sometimes, when boiled with the turpentine, it will mix, but will not combine with any other varnish that has been less boiled than itself. This varnish is used by japanners, cabinet, and coach painters. Animè is however generally used for cabinet varnish.

Best body copal varnish, for the body parts of coaches and other objects intended for polishing, is made by fusing 8 lbs. of fine African gum-copal, and adding 2 gallons of clarified oil. It must be boiled very slowly for 4 or 5 hours until quite stringy, and be mixed off with 3½ gallons of turpentine.

The foregoing varnishes are made of the finest copal without the addition of driers; they are the palest and best of their kind, and have great fluidity and pliability. They are, however, slow in drying, and it requires months for them to become hard enough to polish well. If the varnish is not required to be very pale, gum of second quality is used, and if required to dry quickly, sugar of lead or white copperas, singly or together, are used in the proportion of ½ lb. to 1 lb. to each of the quantities given in the recipes; but the brilliancy, colour, and durability of varnishes are injured by the introduction of driers. If the varnish be required to dry and harden quickly without

the use of driers, animè may be used instead of copal, but it does not form so durable a varnish, and it becomes darker by age. Animè varnish may be mixed with copal varnish in certain proportions, while both are hot. A moderately quick drying body-varnish may be made by mixing 1 part of animè with 2 parts of copal; for an inferior varnish, drying more quickly, 2 parts of animè to 1 part of copal may be mixed.

Carriage varnish for the wheels and under framework of coaches and other objects not requiring to be polished is made like common body-varnish, only that to 8 lbs. of gum of second quality are used about $2\frac{1}{2}$ gallons of oil and $5\frac{1}{2}$ gallons of turpentine, with driers. This varnish is boiled until it becomes very stringy. Its quality is intermediate between body-varnish and

Wainscot varnish, which is made of 8 lbs. of animè of second quality, 3 gals. of clarified oil, $\frac{1}{4}$ lb. of litharge, $\frac{1}{4}$ lb. of sugar of lead, $\frac{1}{4}$ lb. of copperas. These ingredients must be well boiled until the varnish strings very strong, and it must be mixed with $5\frac{1}{2}$ gals. of turpentine. This varnish, which dries quickly, is used chiefly for house painting and japanning. It may be darkened by the addition of a small quantity of gold size.

Spirit and *turpentine* varnishes are prepared by mixing the resins and the solvent together, and agitating the whole with a stick with a number of pegs or nails driven in near the lower end until the solution is complete. The resins should be dry, and in small pieces, with the impurities picked out: the finest and clearest pieces of the gum are set aside for superior varnishes. Turpentine varnishes are made in quantities of 10 or 12 gallons: spirit varnishes from 4 to 8 gallons. In making the latter, the ingredients are sometimes put into a cask of 8 or 16 gallons' capacity, and mounted so as to revolve upon bearings at the ends. An alternating motion is given to the barrel by passing round it a cord terminating in a cross handle. When the operator pulls this cord towards him the barrel rotates, and winds the cord up in the other direction so as to be ready for a second pull, which, in like manner, winds the cord in the opposite direction, and so on. Agitation must be kept up, or the resin will agglutinate. After 3 or 4 hours, or when the solution is complete, the varnish is left for a few hours to deposit solid impurities, and is then strained through muslin or lawn into bottles. Coarsely pounded glass is sometimes added to prevent the agglutination of the resin. When heat is employed in making spirit-varnishes, the source of heat should be a water or a sand bath, and a still and worm may be used to prevent loss by evaporation, the resins and solvent in the still being kept in motion by a stirrer passing through a stuffing-box in the head. Shell-lac contains a little wax, which is apt to get diffused through the varnish when heat is applied. The inflammable nature of the ingredients will of course suggest the necessity for caution in making spirit-varnishes. The utensils employed must be quite clean and dry.

Best white hard spirit-varnish, such as will bear polishing, is made by adding 2 lbs. of the best picked gum-sandarach to 1 gallon of spirits of wine, and agitating for 4 hours, until the solution is complete. 18 ozs. of Venice-turpentine, (or 9 ozs. if the work is not to be polished,) are to be moderately heated in a water-bath until quite fluid, and added to the varnish to give it body. Agitate for an hour, strain and put into bottles, which must be kept well corked. After remaining undisturbed for a week, the varnish is fit for use. If the clearest and palest pieces of gum be selected, this varnish will be pale enough for white work.

White hard varnish.—(No. 1.) $3\frac{1}{2}$ lbs. of gum-sandarach to 1 gallon of spirits of wine, and when the solution is complete add 1 pint of pale turpentine-varnish, and shake the whole well together. (No. 2.) 2 lbs. of gum-sandarach, 1 lb. of gum-mastic, and 1 gallon of spirits of wine. *White spirit-varnish for violins.*—2 lbs. of mastic to 1 gallon of spirits of wine and 1 pint of turpentine-varnish.

Brown hard spirit-varnish is similar to white hard varnish, only shell-lac is used instead of sandarach. Dissolve 2 lbs. of shell-lac in 1 gallon of spirits of wine, and then add 18 ozs. of Venice-turpentine, warmed. This varnish will bear polishing. Or, 2 lbs. of shell-lac, 1 lb. of sandarach, and 2 ozs. of mastic dissolved in 1 gallon of spirits of wine. A lighter colour is produced with 2 lbs. of sandarach, 1 lb. of shell-lac, and 1 gallon of spirit. When the solution is complete add a pint of turpentine-varnish, and agitate the whole well together. If a pale lac-varnish be required, *white* or *bleached lac* may be used. Lac-varnish may be bleached by Mr. Leming's process:—"Dissolve 5 ozs. of shell-lac in a quart of rectified spirits of wine; boil for a few minutes with 10 ozs. of well-burnt and recently heated animal charcoal, when a small quantity of the solution should be drawn off and filtered; if not colourless, a little more charcoal must be added. When all colour is removed, press the liquor through silk, as linen absorbs more varnish, and afterwards filter it through fine blotting-paper."[1]

When copal is added to spirit-varnishes in order to increase their toughness and durability (although the advantage of adding copal may be questioned), the copal should be in fine powder, the spirit very strong, and a gentle heat of about 120°, with frequent agitation, should be used. A light-coloured varnish may be made with $\frac{3}{4}$ lb. of shell-lac, $\frac{3}{4}$ lb. of copal, to 1 gallon of strong spirit.

(1) Transactions of the Society of Arts, vol. xlv. In the same volume is a recipe by Mr. G. Field for bleaching lac-varnish by means of chlorine. Dr. Hare has also published a method as follows:—"Dissolve in an iron kettle 1 part of pearlash in about 8 parts of water, add one part of shell or seed-lac, and heat the whole to ebullition. When the lac is dissolved cool the solution and impregnate it with chlorine gas till the lac is all precipitated. The precipitate is white, but the colour deepens by washing and consolidation; dissolved in alcohol, lac bleached by this process yields a varnish which is as free from colour as any copal varnish." The application of the chlorine must be made by a person acquainted with chemistry. Hence chloride of lime is safer as a bleaching agent, the lime being afterwards dissolved out from the precipitate by the addition of muriatic acid. The precipitate is to be washed several times, dried and dissolved in alcohol with the addition of a little mastic. This varnish is very pale, but rather thin.

Mastic varnish for paintings is generally made by adding 3 lbs. of mastic to 1 gallon of turpentine. The mastic should be carefully picked and dissolved without heat. After straining, the varnish should be kept in a bottle, loosely corked, and exposed to the sun and air for a few weeks. A deposit takes place, and the clear varnish may be poured off, but it improves by age. Mastic varnish is liable to *chill* from the presence of moisture; but this may be carried down by adding ½ pint of well-washed hot sand to each gallon of varnish, agitating for 5 minutes, and allowing to settle.

Turpentine varnish.—Dissolve 4 lbs. of common resin in 1 gallon of oil of turpentine at a gentle heat in the sand-bath. The usual plan, however, is to dissolve the resin in the gum-pot. For a pale varnish, bleached resin may be used at a very moderate heat. Turpentine-varnish is used for indoor painted works, and common painted furniture and toys. It also adds to the body, hardness and lustre of other varnishes.

Crystal varnish for maps, prints, coloured drawings, &c.—Dissolve 2 lbs. of mastic, 2 lbs. of damar, without heat, in one gallon of turpentine; or mix Canada balsam and oil of turpentine in equal parts. Warm the balsam until quite fluid and add the turpentine, agitating for a few minutes; then leave the varnish in a moderately warm place for a few hours, and it will be ready for use the next day. A coat of thin crystal varnish applied to one or both sides of good tissue or foreign post paper, furnishes *tracing paper* of medium quality.

Paper varnish for paper hangings, &c.—4 lbs. of damar to 1 gallon of turpentine. White or bleached resin may also be used, alone, or mixed with the damar.

Water varnish.—Lac is soluble in a hot alkaline solution, and furnishes a varnish that will bear washing. The alkali deepens the colour of the varnish, but ammonia does so less than borax, potash or soda. 16 ozs. of liquor ammoniæ to 7 pints of water, with 2 lbs. of pale shell-lac and 4 ozs. of gum arabic, give a pale water varnish. Borax is, however, commonly used in the proportion of 2 lbs. of shell-lac, 6 ozs. of borax, 4 ozs. gum arabic, and 1 gallon of water. White lac is used for the palest water varnishes.

Sealing-wax varnish for coating apparatus, &c.—Dissolve 2½ lbs. of red sealing-wax and 1½ lb. of shell-lac in 1 gallon of spirits of wine.

Black varnish.—3 lbs. of black sealing-wax and 1 lb. of shell-lac to 1 gallon of spirit: or mix fine lamp-black with brown hard varnish or lacker. Such a varnish is used for blackening the interior of telescope tubes, the lamp-black serving to deaden the bright colour of the lacker. A black varnish for metal works may be made by fusing 3 lbs. of asphaltum, and ½ lb. of shell-lac, and adding 1 gallon of turpentine.

Our space will not admit any more recipes for varnishes, but we may conclude this part of our subject with Mr. Neil's general remarks on the making of copal varnishes. He says,—"The more minutely the gum is run or fused, the greater the quantity and the stronger the produce. The more regular and longer the boiling of the oil and gum together is continued, the more fluid or free the varnish will extend on whatever it is applied. When the mixture of oil and gum is too suddenly brought to string by too strong a heat, the varnish requires more than its just proportion of turpentine to thin it, whereby its oily and gummy quality is reduced, which renders it less durable; neither will it flow so well in laying on. The greater proportion of oil there is used in varnishes, the less they are liable to crack, because the tougher and softer they are. Increase the proportion of gum in varnishes, the thicker the stratum, and the firmer they will set solid and dry quick. When varnishes are quite new made, and must be sent out for use before they are of sufficient age, they must always be left thicker than if they were to be kept the proper age."

Varnishes are applied to flat surfaces with soft clean brushes, and for spirit varnishes camel's hair pencils and brushes are used. The varnish should be applied in very thin coats, sufficient time being left between two coats for the solvent to evaporate. Spirit varnishes require 2 or 3 hours between every two coats, turpentine varnishes 6 or 8 hours, and oil, varnishes 24 hours; but the state of the atmosphere will require these intervals to be varied. The second coat should never be added until the first is quite hard. Care must be taken not to allow dust or loose hairs from the brush to get attached to the varnish: if hairs, &c. do get on, they must be carefully picked out with the point of a knife before the varnish dries, and the surface of the varnish be levelled with fine glass-paper before the next coat is put on. A dry, moderately warm atmosphere (such as that indicated by a temperature of 72°) is required for varnishing, and especially for spirit-varnishing, where the presence of moisture causes a slight precipitation of the resin, producing the effect that is called *chilling* as already noticed; whereas if the air be kept quite dry during the evaporation of the spirit, the resin is left on the surface as a thin glassy coat, which is no longer influenced by moisture, but acts as a perfect transparent protection to the surface to which it has been applied. Cold draughts will also produce the effect of chilling. When the varnish has been chilled, it may often be restored to its required lustre by applying a thin coat of varnish and placing the object at such a distance from the fire as partially to dissolve the chilled coat. Care must, however, be taken not to raise blisters. The articles to be varnished should be smoothed with fine glass-paper, and minute holes in the wood should be stopped with gum or wax. The varnish is usually contained in an ordinary preserve jar, with a wire or string drawn across the top for drawing the brush against so as to reduce the quantity taken up. Enough varnish should be kept in the jar to cover the hairs of the brush; should the varnish become too thick by evaporation it may be thinned down by the addition of spirits of wine, and in general a better effect is produced by the application of a number of thin coats than of a few thick ones. Spirit varnishes should be put on rapidly, and

be well worked in so as to exclude minute air-bubbles. Some skill is required to produce a uniform effect, especially in large surfaces. The first coat of varnish is generally absorbed more or less by wood and porous surfaces, and the absorption raises the grain of the wood, so that a second and even a third coat may be required to fill up the pores uniformly. The work is then smoothed with fine glass-paper, and 2 or 3 coats of varnish are afterwards applied. As the absorption of the first layers produces a great expenditure of varnish, it is sometimes usual to substitute for the first layers size made of pale glue or parchment cuttings, or solutions of isinglass or tragacanth. Turpentine and oil varnishes are applied generally in the same manner as spirit varnishes, but as they dry more slowly it is easier to produce a uniform effect on large surfaces with them than with spirit varnishes. Coloured works receive their coat of colour before being varnished.

The finest kinds of varnish-works, such as the wooded work of harps, is thus performed:—"The wood is covered with about 6 layers of the white hard varnish, and allowed thoroughly to dry between each; this entirely fills up the pores of the wood; the face is then rubbed quite smooth with fine glass-paper. The ornamental painting is then done, after which about 8 or 10 coats more of varnish are laid on, and at every third coat the surface is rubbed with fine glass-paper to remove the brush marks. When all the varnish is put on and has become hard, the surface is rubbed with fine pumice-stone powder and water on woollen rags; the work is allowed to stand for a day or two, and is then polished with yellow tripoli [1] and water, after which it is washed quite clean with a sponge and wiped dry with a clean wash-leather. The varnish is now touched at a few places with the finger smeared with fine rendered tallow, which is then thoroughly rubbed all over with the ends of the fingers; clean wheat flour is dusted over the work, and also well rubbed in with the fingers; and after the removal of the flour, the surface is slightly rubbed with a clean old silk handkerchief, which completes the splendid lustre given to these instruments." [2]

VAULT. See Bridge.

VEIN. See Mine—Mining.

VEINSTONE or GANGUE. See Mine—Mining.

VELLUM. See Parchment.

VELVET. See Weaving.

VENEER—VENEERING. The art of covering a cheap and inferior wood with a thin layer of wood of a more ornamental and costly character is not a modern invention. The elder Pliny refers to it as a recent invention in his time, suggested doubtless by the large sums which the luxurious Romans were accustomed to pay for solid tables of rare and costly woods. [3] Pliny speaks of the ingenious art of converting the cheaper into the most valuable woods, by plating them with the latter, so that by cutting a tree into thin slices, it may thus be sold several times over.

In the cutting of veneers, it is of course desirable to economise the material as much as possible, and hence it is now usual to employ very accurate machinery for the purpose. They were formerly cut at the saw-pit, with very thin plates strained in the common pit-saw frame [see Saw], or they were cut with the smaller frame-saw, as is now done on the Continent. Skilful pit-sawyers would cut 6 veneers out of every inch of wood, and cabinet-makers 7 or 8 from smaller pieces, but as the veneers increased in size the difficulties of cutting them accurately were greatly increased. Small veneers for the backs of brushes, &c. were split or planed from small pieces squared to the required sizes. The scale-boards for making hat and bonnet boxes are cut by a Planing-machine, as noticed under that head. The method of producing continuous shavings of this kind is important where the material is costly, for the ordinary veneer-saw cuts on the average one-third of the material into saw-dust. It is said to have originated in Russia, and by its means the veneers are cut spirally from a cylinder of wood with a knife of the same length as the cylinder. Ivory has been cut in this way into sheets of large dimensions. Pape, of Paris, some years ago, veneered a piano-forte entirely with ivory, and advertised to supply sheets as large as 30 by 150 inches. In the United States department of the Great Exhibition was an ivory veneer 12 inches wide, and 40 feet long, cut out of a single tusk. In 1806, Mr. Brunel patented a method of splitting veneers of large size by means of a horizontal knife composed of several pieces of steel placed exactly in a line on their lower surfaces, but with their edges slightly rounded and very keen. A short reciprocating or sawing motion was imparted to this compound knife, and the block of wood to be cut up was carried slowly sideways beneath the knife by means of a screw-slide worked with a spoke-wheel. When one veneer had been cut off and the log restored to its first position, it was raised in exact parallelism by a system of two right-and-left-handed screws at the four angles of the frame, and which were all moved together by means of one winch-handle. This machine answered the purpose when veneers were to be cut from straight-grained and pliant woods, such as Honduras mahogany: but with woods of irregular and brittle grain, such as rosewood, the veneer curled up or split. The circular saw, although so wasteful of the material, is therefore commonly used for cutting veneers; and in order to give the

(1) Tripoli and rottenstone for such works as these are prepared for use by grinding very fine with a stone muller.

(2) Holtzapffel, Mechanical Manipulation, vol. iii. There is a long and instructive chapter in this volume on Varnishing, Lackering, Japanning, Bronzing, &c.

(3) The most costly wood in the time of Cicero, was procured from a tree named *citrus*, a native of Mauritania, near Mount Atlas. In leaf, trunk, and odour it resembles the female wild cypress; the most valuable part is a tuber or warty excrescence, which when found on the root and underground is more esteemed than when growing on the branches. When cut and polished, it presents various figures, such as curling veins, or concentric eye-like spots; the former have procured for the wood the name of tiger-wood, the latter panther-wood. A table of this kind is said to have cost Cicero a million of sesterces, or £8,072 sterling. Even higher prices are quoted for the solid tables. See Mr. Aikin's paper on "Ornamental Woods," in the Transactions of the Society of Arts, vol. l.

saw sufficient strength, it is made thick towards the centre, and towards the edge it is thinned away almost to a feather edge. The solid block of wood or ivory is conducted along a parallel guide across the flat face of the saw, while the thin pliant veneer separates and forms an opening for the wedge-shaped edge of the blade, the veneer passing uninterruptedly along the conical back of the saw. For cutting large veneers, the saw is composed of a number of segments or plates of steel screwed to the edge of a metal disk, cast-iron wheel, or chuck, and is sometimes as much as 18 feet in diameter. In all veneer saws the edge must run very true, and the teeth must be sharp and very faintly set. [See SAW.] If the segment veneer-saw exceeds about 4 feet in diameter, the horizontal platform or table is not used for guiding the wood, but a contrivance called the *drag*. In saw-mills where veneers are cut, the arrangement of the segment saw is called a *veneer-mill*. The axis of the saw runs in massive brasses, fixed on brick or stone piers; and if the saw be large, its edge is made to dip into a pit below the ground. The axis of the saw is connected or disconnected with the moving power by means of a fast-and-loose pulley. The log of wood is usually adzed over to remove sand and dirt, and is then partially levelled to adapt it to the vertical face of the drag. The log is held by iron fastenings or *dogs*, while its surface is levelled by the saw; it is then glued to a wooden frame containing transverse and oblique bars, which have also been levelled with the saw. By this arrangement, the whole log can be cut into veneers without interruption from the joint. The timber is carried across the face of the saw by means of a rack and pinion acting on the drag, which is supported on a railway extending across the face of the saw. The axis of the pinion is furnished with a double train of toothed wheels, and a clutch-box, the latter capable of being adjusted to 3 positions, by which the drag may be at rest or be carried slowly past the saw, or returned quickly back preparatory to another cut. The lever by which these motions are given is placed just behind the stool on which the workman is seated. Between every two veneers, the block requires to be advanced sideways through a small space equal to the thickness of the intended veneer. This is accomplished by means of adjusting screws, which act upon the standards which support the frame or wooden bars to which the wood is attached. The adjusting screws have worm-wheels at one end, and are simultaneously moved by a winch-handle, 50 or 60 turns of which are required to advance the log 1 inch, so that the veneers can by this adjustment be cut to any desired thickness. The thin veneer as it is cut is guided away from or in front of the saw by a feather-edged brass guide-plate, fixed almost in contact with the blade of the saw. As the veneer is being cut, the workman leads it on to the guide by means of a thin blunt chisel or *spud;* and it passes over the guide through a curved wooden trough, and when fully detached, it is removed and placed in a heap of veneers already cut from the same log. The teeth of the saw are cleared of saw-dust by means of a *freeing-stick* applied beneath the timber during the action of the saw.

The number of veneers cut out of each solid inch of wood varies with the width of the veneers, and the purpose to which they are to be applied. In general, when the width of the wood is 6, 12, 18, 24, 30, 36, 48, 60 inches, each inch of wood is cut into 15, 14, 13, 12, 11, 10, 9, 8 veneers.

As the veneers are cut they are rough on both sides, in which condition they are used by cabinet-makers for veneering articles of furniture. The operations of veneering consist in glueing the veneer to the prepared surface, and cleaning and polishing it when so fixed. Suppose the top of a table or of a sideboard is to be veneered. The workman first cuts out his veneers a little larger than the required size to allow for waste; he also cuts out a *caul* or board to prevent the clamp screws from leaving marks, and he next proceeds to scratch over the surface of the table or sideboard, and both surfaces of the veneer, with an iron *toothing-plane*, which gives to the surfaces the required roughness, or *tooth*, or *key*, as it is called, for holding the glue. The clamps consist of strong wooden bars somewhat rounded on their inner edges, and connected by iron screw-bolts and nuts. The surface of the table being warmed, and the veneer and caul made hot, the table is brushed over with thin glue; the veneer is also glued and placed on the table: upon the veneer is put the heated caul, and the clamping bars are next quickly screwed down 3 or 4 inches apart. The heat of the caul retains the glue in a fluid state during the screwing down, which operation brings every part of the veneer into contact with the table, and forces out most of the glue. The table is generally left all night before the screws are removed. For curved work the cauls are also curved, and the clamp screws are numerous, in order to multiply the points of pressure.

Veneers are sometimes laid with a veneering hammer, which is a hammer with a very wide and thin pane; or simply a piece of wood 3 or 4 inches square, with a round handle projecting from the centre: one edge of the head is sawn down for the reception of a piece of sheet-iron or steel, which is made to project $\frac{1}{4}$ inch, with a straight, smooth, round edge, and the opposite side of the square head is rounded to make it fit the hand better. The table and both sides of the veneer are toothed, the surface of the table is warmed, and the outer face of the veneer and the surface of the table are wetted with thin glue or stiff size. The inner face of the veneer is next glued, and the veneer is held for a very short time before a blazing fire to make the glue very fluid; the veneer is then turned down upon the table and rubbed down by hand, several men being employed if the veneer be of large size. The greater part of the glue is then forced out with the edge of the veneering hammer, which is placed in the centre of the table, and gradually worked to the edge. A number of men are employed on this at once, and in order to keep the glue fluid, as also to relieve the friction of the hammers, hot size is occasionally applied to the surface of the veneer. When

the work is judged to be complete, it is tapped all over with the back of the hammer; if the sound be anywhere hollow or *tacky*, the contact is imperfect, and the hot size and the work of the hammer must be repeated; or if the glue be well set, the inner vessel of the glue-pot, or a hot iron, must be applied to the spot to melt it. Should the glue be in excess at one spot, the hot iron must be slowly moved towards the edge, so as to form a kind of channel along which the glue is pressed by the edge of the veneering hammer.

INLAYING is a species of veneering in patterns which are cut with the buhl-saw, or piercing-saw, Fig. 381. [See BUHL-WORK.] As an example of buhl-work in wood we take the liberty of quoting Mr. Holtzapffel's excellent description of the mode of forming the honey-suckle ornament. "To make this, two pieces of veneer of equal size, say of ebony and holly, are scraped evenly on both sides with the toothing-plane, and glued together with a piece of paper between, for the convenience of their after-separation. Another piece of paper is glued outside the one or other veneer, and on which the design is sketched; a minute hole is then made with a sharp-pointed awl or scriber, for the introduction of the saw, that spot being selected in which the puncture will escape observation. The buhl-cutter being seated on the horse, the saw is inserted in the hole in the veneers, and then fixed in its frame; the work, held in the left hand, is placed in the vice, which is under control of the foot, and the saw is grasped in the right hand, with the fore-finger extended to support and guide the frame; the medium and usual position of which is nearly horizontal and at right angles to the path of the saw. The several lines of the work are now followed by short quick strokes of the saw, the blade of which is always horizontal; but the frame and work are rapidly twisted about at all angles, to place the saw in the direction of the several lines. Considerable art is required in designing and sawing these ornaments, so that the saw may continue to ramble uninterruptedly through the pattern, whilst the position of the work is as constantly shifted about in the vice, with that which appears to be a strange and perplexing restlessness. When the sawing is completed, the several parts are laid flat on a table, and any removed pieces are replaced. The entire work is then pressed down with the hand, the holly is stripped off in one layer with a painter's palette-knife, which splits the paper, and the layer of holly is laid on the table with the paper downwards, or without being inverted. The honeysuckle is now pushed out of the ebony with the end of the scriber, and any minute pieces are picked out with the moistened finger; these are all laid aside; the cavity thus produced in the ebony is now entirely filled up with the honeysuckle of holly, and a piece of paper smeared with thick glue is rubbed on the two to retain them in contact. They are immediately turned over, and the toothings, or fine dust of the ebony, are rubbed in to fill up the interstices; a little thick glue is then applied, and rubbed in, first with the finger, and then with the pane of the hammer, after which the work is laid aside to dry. When thoroughly dry, it only remains to scrape the bottom with the toothing-plane, or, when the work is small, with its iron alone, and then the buhl is ready to be glued on the box or furniture in the manner of an ordinary veneer, as already explained; when the work is again dry, it is scraped and polished. Exactly the same routine is pursued in combining the holly-ground and the ebony honeysuckle, and these constitute the *counter*, or *counterpart buhl*, in which the pattern is the same, but the colours are reversed. It is obvious that precisely the same general method would be pursued to make 4 satin-wood honeysuckles at the respective angles of a rose-wood box; the veneers for which would then be selected of the full size, and glued together with paper interposed. To ensure the exact similitude of the several honeysuckles, one of them having been cut out would be printed from, by sticking it slightly to the table, dabbing it with printing-ink, and then taking impressions to be glued on the other angles of the box at their exact places. The counter would have, in this case, a satin-wood ground, with the honeysuckles in rose-wood. To advance another stage, 3 thicknesses of wood may be glued together, as rose-wood, mahogany, and satin-wood, and a centre ornament added to the group of 4 honeysuckles. The 3 thicknesses, when cut through, split asunder, and re-combined, would produce 3 pieces of buhl-work, the grounds of which would be of rose-wood, mahogany, and satin-wood, with the honeysuckle and centre of the two other colours respectively. Such are technically known as 'works in three woods,' and constitute the general limit of the thicknesses, but the patterns consist of many more parts than are here supposed."[1] See MARQUETRY.

VENTILATION. See WARMING AND VENTILATION.

VERATRINE or VERATRIA, an alkaloid contained in the seeds of *Veratrum sabadilla*, and in the roots of *V. alba*, or *white hellebore*. It is a white or yellowish-white powder, with a sharp burning taste: it is poisonous; and is remarkable for occasioning violent sneezing. It is insoluble in water, but dissolves in hot alcohol, in ether, and in acids: and the solution has an alkaline reaction. Veratria is said to contain $C_{34}H_{22}O_6N$.

VERDIGRIS. See COPPER.

VERDITER. See COPPER.

VERMICELLI. See MACARONI.

VERMILION. See MERCURY.

VIADUCT. See BRIDGE—ROADS AND RAILROADS—AQUEDUCT.

VICE, a well-known contrivance for fixing work during the filing or otherwise shaping thereof.[2]

(1) "Mechanical Manipulation," vol. ii. As an example of complex inlaying, Mr. Holtzapffel gives an engraving of a border of flowers on a black ground of ebony, with instructions for making it. The green leaves are of holly, stained green, notched and engraved. The petals are of holly stained blue, or scorched; white holly, yellow Zante, and red Brazil wood are also used.

(2) A large number of vices are described and figured in Holtzapffel's "Mechanical Manipulation," chap. xxviii. sec. 3.

VINEGAR. See ACETIC ACID.

VITRIFIABLE COLOURS. See GLASS, Sec. ix. —POTTERY AND PORCELAIN, Sec. viii. ix.

VITRIFICATION. See GLASS—POTTERY AND PORCELAIN.

VITRIOL. See SULPHUR, page 800, note.

WACKE, or GRAU or GREYWACKE, a term adopted from the German geologists, and applied to some of the ancient stratified rocks. When the term is applied to particular rocks, it bears nearly the same relation to clay slates that argillaceous sandstones and conglomerates bear to common clays; "for argillaceous slate," as Mr. Phillips remarks, "by including rolled fragments or minute grains of quartz sand, with or without mica, becomes the *grauwacke*, and *grauwacke-slate* of Werner and his followers. When the sand or gravel predominates, so as nearly to exclude the argillaceous cement, the distinction between grauwacke and sandstone is almost imaginary, just as, on the other hand, indurated shale and soft clay-slate are not always certainly distinguishable." The grauwacke rocks lie amidst the primary argillaceous strata, and form part of the *transition series* of continental geologists. The *grauwacke group* of De la Beche includes the *Silurian rocks* of Murchison, and a portion of the older strata called the *Cambrian rocks* by Sedgwick.

WAD, a term applied by miners to a soft black mineral, the hydrate of the peroxide of manganese.

WADDING, a spongy material used for lining ladies' dresses; it is made with a lap of cotton prepared by the carding-engine, or lap-machine, [see COTTON, Fig. 637]; and is attached to tissue paper by means of size.

WAFERS. The invention of wafers is attributed to the Genoese; but long before their application to the sealing of letters, they were made by the pastry-cook in the form of a thin curled-up cake. Indeed, a pastry-cook was formerly called a *wafirer*. According to Beckmann, the oldest seal with a red wafer is on a letter written by D. Krapf, at Spires, in the year 1624, to the government at Bayreuth. It appears that wafers were not used during the seventeenth century in the chancery of Brandenburg, "because people were fonder of Spanish wax." By an order dated 1716, the use of wafers in law matters was forbidden in the duchy of Weimar; but this order was abolished in 1742. See SEALING-WAX.

The French term for wafers, *pains à cacheter*, indicates the materials of which they are made. Wafers are small disks of dried wheaten paste, to which an adhesive property is instantly communicated on the addition of moisture. In the manufacture of wafers fine wheaten flour is formed into a smooth paste, with the addition of colouring matter and sometimes of a small quantity of white of egg and isinglass. This paste is baked in thin layers, between two plates of iron attached to handles, which are hinged together like snuffers or curling-tongs. The lower plate, which is furnished with a slightly raised ledge, forms a mould for the paste. The plates are warmed, and slightly greased, and a portion of the paste being poured into the lower plate, the top plate is shut down, whereby the paste is formed into a thin layer of equal thickness, the superfluous portion being squeezed out. The instrument is then held in the fire for a few seconds, when it is perfectly baked, and by exposure to the air it soon becomes dry and brittle. A number of these plates of paste being collected into a heap, the wafers are cut out by means of hollow punches of various sizes. Some of the mineral colours employed to colour wafers being poisonous, the refuse is sold for the purpose of destroying rats and other vermin.

Medallion wafers, containing a classic design on a ground of a deeper colour, were in fashion some years ago. They were formed in the following manner:—Pure glue was dissolved in water, and the colouring matter added. A gem, seal, or medallion was next moistened with a weak solution of gum, in which an opaque white, or other colour had been dissolved; this coloured gum water was carefully wiped off the smooth uncut surface of the seal, and a small quantity of the coloured glue was poured over the seal, and left to dry at a gentle heat. In drying, the glue and gum contracted, and were thus easily separated from the seal, thus forming a wafer not thicker than writing paper, and affording a beautiful imitation of the device, the coloured gum giving the figure, and the glue the ground. On wetting the back of the wafer, it adhered to and secured a letter just like an ordinary seal.

The French *isinglass wafer* was prepared by dissolving isinglass in water, and pouring it upon glass plates with raised borders, previously smearing the plates with ox-gall, to prevent the isinglass from adhering. Various colouring matters, and even perfumes, were mixed with the fluid isinglass. When the film on the plate was evenly distributed, a plate of glass was placed upon it, and the film was thus moulded into a fine delicate sheet: before it was quite dry, it was cut along the edges, and separated, and afterwards cut into wafers in the usual manner. These wafers were exceedingly thin, and far more adhesive than common wafers. *Gelatine wafers* are now largely manufactured in a similar manner. See GELATINE.

WALKING WHEEL. See PEDOMETER.

WALL. See BRICKLAYING—MASONRY—BRIDGE —ROADS AND RAILROADS.

WARP. See WEAVING.

WARMING AND VENTILATION. The art of warming *or* of ventilating a building is not a difficult one; but the art of warming *and* ventilating is extremely difficult, and cannot be said to have attained to anything like perfection. And yet there is no art of greater importance, for on it depend the health, the comfort, and much of the prosperity of man, and of the animals which he domesticates for his use and profit.

In order to arrive at satisfactory results in the practice of this art, it is necessary to be well acquainted with the chemical conditions of the problem which is to be solved. Now it is well known that the combustion of fuel and the respiration of animals are processes almost chemically identical; they require

for their successful performance a constant supply of oxygen gas, which, under ordinary circumstances, is afforded by the atmospheric air. The carbon of the fuel which we burn for the sake of heat, and the carbon of our candles, oil-lamps and gas-jets which we burn for the sake of light, is converted into carbonic acid. So also with respect to the food consumed by animals, a portion of its carbon is employed in the generation of animal heat; and during its slow combustion, is converted into carbonic acid. While oxygen gas is passing inwards through the membrane of the lungs, carbonic acid is passing outwards through the same membrane. The oxygen of the air is absorbed by the blood in the ultimate vessels of the lungs, and in some unknown state of combination reaches the extreme subdivision of the arteries, where it unites with a portion of carbon and forms carbonic acid gas, which gas also, in some unknown state of combination, is retained in the venous blood, until it is expelled in the lungs and oxygen absorbed in its stead. A man of ordinary stature consumes in the course of 24 hours, 9 ounces troy, of carbon; the consumption of oxygen in this process is equal to 24 ounces, or 19·4 cubic feet; the quantity of air vitiated in the process amounts to 97·2 cubic feet, and the product in carbonic acid to 33 ounces. The products of combustion and of respiration consist therefore chiefly of carbonic acid mingled with the nitrogen of the air, both irrespirable gases, which, unless largely diluted with air, would, if taken into the lungs, produce death. Now, in the economy of nature, it has been wisely ordained that these poisonous products of such extensive processes as combustion and respiration shall form an aerial manure to the vegetable kingdom, supplying it with materials for growth; and the organs of plants are so constructed, that in appropriating and assimilating this aerial manure, they return fresh supplies of pure oxygen to the atmosphere; they inhale carbonic acid, and exhale vital air. Nature has also wisely provided that the air vitiated by combustion shall have a strong ascensive force due to its high temperature, in virtue of which it ascends into the atmosphere, where it is wafted by the winds, or absorbed by the rain, and thus distributed over the vegetable kingdom. So also with respect to the products of respiration. The vitiated air as it leaves the chest, has nearly the temperature of the blood, viz. 98°, and thus being specifically lighter than the surrounding air, it ascends and escapes to a higher level. In the open air the process is perfect, because there is no impediment to the ascent of the vitiated air; but in rooms, halls, churches and similar enclosures, as ordinarily constructed, the vitiated air, whether arising from combustion or respiration, rises up to the ceiling, and cannot escape, but accumulates, becomes cooler, and thus descends and mingles with the fresher air which occupies the lower level.[1] The inmates of the apartment thus have to inhale an atmosphere which is every moment becoming more impure; and it is only because the doors and windows do not fit tightly that suffocation does not result. But what an amount of suffering is endured in every public assembly, and in most private apartments, from the occupants having to inhale the poisonous products of combustion and respiration, mingled as they are with animal effluvia of the most offensive description! It is only because these products are invisible that they fail to attract attention, except on the part of chemists, and certain intelligent persons who believe that chemists have rightly interpreted the laws of nature. In fact, the products to which we refer are excrements of the most offensive and deadly kind, which once discharged from the system cannot with impunity be admitted into it again.

(1) A good illustration is afforded of this process in blowing out a tallow candle. The hot nauseous vapour ascends to the ceiling, spreads all over its surface, becomes cooled, and then descends to taint the air of the whole apartment.

If every ceiling were provided with openings for the escape of the vitiated air from the room to the outside of the building, we should be spared many a headache, many a nervous attack, many a fever; our lives would be more enjoyable, our intellects clearer, and our morals purer; for we have no doubt that the breathing of a pure air is as necessary as the enjoyment of good food and competence to the possession of a cheerful temper and an innocent frame of mind. But there are difficulties about having an opening in the ceiling with a channel leading to the outer air. 1. The room would not be so warm, for it is obvious that the escape of hot, although vitiated, air would materially lower the temperature of the apartment. 2. Occasions might arise when the channel would bring in cold air and pour it down in a stream upon the heads of the inmates, instead of letting out hot air. 3. Such a channel would admit noise from the street. We will endeavour in the course of this article to show how this contrivance may be modified, so as to overcome these objections. The principle, however, is sound, that in ventilating an enclosed space, the hot vitiated air must find an exit at the highest point of the enclosure, and the supply of fresh air be admitted at or near the lowest point.

We are so accustomed to the open fire-place, and the extravagant waste of valuable fuel which it entails, that we are apt to look with suspicion on other contrivances for warming our rooms. It is necessary, however, to inquire a little into the various methods of obtaining artificial heat before we can affirm that the open coal fire is the best method. The first part of this article will therefore be devoted to a notice of various contrivances for warming buildings; the second part to the means of ventilating; and the third part to the art of warming and ventilating.

Section I.—On the various means adopted for the warming of buildings.

1. *By the open fire.*—That large proportion of the human race which inhabits extratropical climes, and requires the use of means for the production of artificial heat during a greater or less portion of the year, is influenced both morally and physically by the facilities with which fuel can be procured. Where the

climate is severe and fuel is scanty, men suffer great privations, and the race declines both in mind and body. Where fuel is abundant man thrives; his houses are larger than in the former case, and he can afford to shelter comfortably many domestic animals, so that he is not pinched for want of food. It is stated that in France, where fuel is scarce, the average height of a man does not exceed 5 feet 4 inches; that in the Netherlands, where fuel is more abundant, the average height is 5 feet $6\frac{1}{3}$ inches; that in England, where fuel is abundant, the average height is upwards of 5 feet 9 inches, and that in Sweden, where wood is very abundant, the peasants are tall vigorous men notwithstanding their uncleanly habits and the rigour of the climate.

In some parts of China where fuel is scarce, the inhabitants resist the cold of winter by means of warm clothing, and this is a safer method than that which we are accustomed to adopt, since with them the defence is constant and uniform, while with us the in-door clothing is thin, and the atmosphere of our rooms is raised to summer temperature. Provided a person be well clothed he can breathe the coldest air with safety and even with an exhilarating effect, as in skating or in walking briskly. We may enjoy a comfortable warmth in bed while the air of the room is cold enough to freeze water. Hence it is better to dress so as to feel comfortably warm in a room heated to 60° or 62°, which it is not dangerous to enter or to leave, than to dress lightly in a room heated to 70° or more, and which is liable to sink to 50° or less.

In most cold countries the poor obtain warmth by some means or other which renders the air almost irrespirable. The poor lace-makers of Normandy work all night in houses where cows are tethered, for the sake of the steaming animal heat. The Laplander during two-thirds of the year occupies a small hut heated by a smoky lamp of impure oil. The Greenlander occupies a larger and better contrived hut, but it is often occupied by half a dozen families, each of which is provided with a lamp, and a traveller remarks, that the effect of this arrangement "is to create such a smell, that it strikes one not accustomed to it, to the very heart." In Persia, a large jar, named a *kourcy*, sunk in the earthen floor of the room, is filled with wood, dried dung or other combustible, and when sufficiently charred the mouth of the vessel is shut in with a square wooden frame, and the whole is covered with a thick quilt, around which the members of the family sit, placing their knees under it so as to allow the hot vapour to insinuate itself into the folds of their clothing. When one desires more warmth he reclines with the quilt drawn up to the chin. In some parts of Spain charcoal is burnt in a flat open brass pan about 2 feet in diameter, raised a few inches from the ground by a round wooden frame for supporting the feet of those who sit near. The charcoal brazier is a very ancient method of warming an apartment: the Greeks of old adopted it, and bestowed much of their exquisite taste in improving the form of the brazier and adorning it with sculptured figures. We still admire the elegant bronze tripods of the Romans, supported by satyrs and sphinxes, with a round dish above for the fire, and a small vase below for holding perfumes. It is strange that the charcoal brazier should still continue in use; it has long been employed as the instrument of suicide, and has also led to many involuntary deaths; and the cause is well known. A pound of charcoal in burning consumes $2\frac{6}{10}$ lbs. of oxygen, which is the quantity contained in between 13 lbs. and 14 lbs. of atmospheric air. A room 20 feet by 13 and 10 feet high contains about 200 lbs. of air, and as the combustion of 1 lb. of charcoal produces $3\frac{6}{10}$ lbs. of carbonic acid, which by mingling with the rest of the air of the room renders at least 36 lbs. of air unfit for respiration, making in all about 50 lbs. weight of air, it is evident that in a room thus heated, death will ensue unless the ventilation be sufficient to change the whole of the air many times within the hour.

The Romans, however, adopted a much better plan than that of the brazier for heating large rooms, viz. the *hypocaust*, or a system of flues conducted below the floor, the fireplace being outside the building. A similar contrivance is still in use among the Chinese in and about Pekin. The fireplace is formed against the exterior wall of the room which is to be heated, or in an adjoining room. From the fire or the fire-chamber proceeds a main flue opening into a horizontal flue *a b*, Fig. 2230, from which proceeds a second flue *c d* at right angles thereto; these flues are perforated at intervals for the purpose of diffusing the smoke and hot air over the under surface of the tiled floor, and the smoke finally finds an exit by two horizontal flues *e f* attached to the side walls.

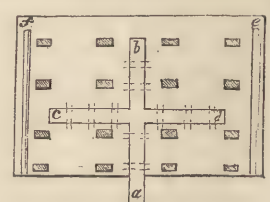


Fig. 2230.

The tiles of the floor, being bad conductors of heat, retain sufficient warmth for domestic comfort long after the fire is extinguished. Benches and sleeping places are similarly warmed. They are built hollow with bricks in a square or oblong form, and communicate with the flues. Inferior or small refuse coal is used for this source of heat: it is mixed with a compost of clay, earth, cowdung or other refuse vegetable matter; then formed into balls and dried in the sun. These balls give out very little smoke, and are well adapted for the purpose intended. The horizontal flue is termed a *ti-kang;* in the *tong-kang* the flue is vertical, and approaches the chimney in its form and action.

Before the introduction of this important contrivance, the chimney, the old baronial hall was heated by a fire in the middle, and in the roof above was a turret or louvre filled with boards arranged so as to exclude the wind and the rain and allow the smoke to escape. The houses of the small land-holders and farmers were usually one story high; the hall and the kitchen formed one apartment, which was open to

the timbers of the roof, and in some cases was furnished with a louvre, and a window that could be closed with a shutter. Cottages had no louvre. The castles which were built about the time of the Conquest were several stories in height, and the roof being a flat terrace, the central hearth and louvre could not be constructed. The fire hearth was therefore transferred to the wall, which was perforated to afford an exit to the smoke, and thus the chimney came gradually to be introduced. See CHIMNEY.

Wood was the ordinary fuel up to the seventeenth century, or long after the introduction of the chimney. It was burnt on a spacious hearth, the logs being

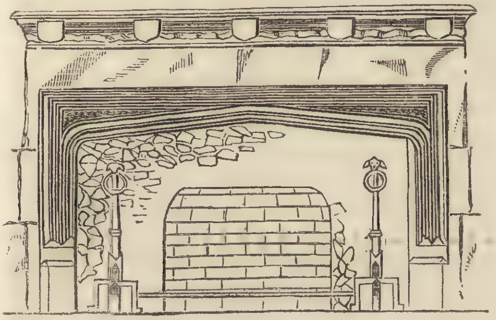


Fig. 2231.

confined between 2 standards of the andiron, Fig. 2231, their ends resting on the billet bar so as to allow air to be admitted below. The standards were variously ornamented with brass rings, knobs, rosettes, heads and feet of animals, and grotesque forms. In kitchens and the rooms of common houses the andiron, as its name implies, was of iron; but in the hall the standards were of copper or brass, and sometimes of silver. The capacious receptacle was furnished with seats on each side of the hearth, and the chimney corner was the post of ho-

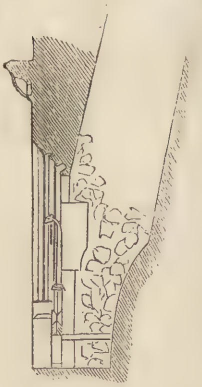


Fig. 2232.

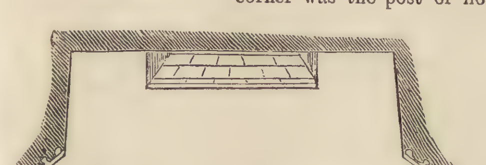


Fig. 2233.

nour. The place of assembly of the family was round the hearth, which thus becoming associated with ideas of comfort and conviviality, the word *hearth* became synonymous with *home*. In smaller rooms where the fire was made in a wide and deep recess each standard was fixed into the back of the hearth by a lateral bar, as shown in Figs. 2231, 2232, 2233, which represent an elevation, section, and plan of the fireplace in the hall at Vicar's Close, Wells.

So long as wood was abundant, coal was not used in Great Britain: indeed, it was long held to be injurious to health; but towards the close of the 13th century, however, coal was imported into London from Newcastle for the use of brewers, smiths, and others, who consumed large quantities of fuel. Its use was regarded with suspicion, and in 1306, parliament petitioned the king to prohibit its employment in the city. A royal proclamation was accordingly issued, forbidding the use of coal. This failed in its object, and a commission was issued for the purpose of ascertaining the names of the persons that burned sea-coal within the city and its neighbourhood, in order that they might be punished, first by fine, and, on a repetition of the offence, by a demolition of their furnaces. But as these severe measures failed to effect the object, a law was passed making the burning of sea-coal within the city a capital offence, and permitting its use only in the forges of the neighbourhood. In the reign of Edward I. a man was actually hung for burning coal in London. It was not until the commencement of the 17th century that the use of coal became general. Ladies supposed that it injured their complexions:[1] and they even objected to partake of food that had been cooked at a coal fire.

There is no doubt that the large chimney recesses, and chimneys adapted to the burning of wood fuel, were not well contrived for the combustion of coal. Improvements, however, were first made in hearths where wood was burnt. Louis Savot, in his *Treatise on Architecture*, remarks that only large rooms are free from smoke, and that when fires are kindled in small rooms a door or window had to be left open to prevent the air coming down the wide flue and driving the smoke into the room. To correct this, Savot raised the hearth about 4 inches, and lowered the mantel, so as to make the opening of the fireplace about 3 feet high: the width between the jambs was reduced to 3 feet, the jambs from the mantel were to be carried up sloping to the *waist*, or where the flue begins to be of uniform width, and the opening of the fireplace was formed like an arch. When the fireplace could not be conveniently altered, a plate of iron, of similar width and length with the hearth, was perforated with small holes, and fixed 3 inches above the tiles of the common hearth: 9 inches above this perforated plate was placed a "grille de fer" of the same length as the billets to be burned. The wood was placed on the grate, the charcoal on the perforated plate, and the hearth received the ashes: the air, rising through the small holes, promoted the combustion of the charcoal, and this assisted the burning of the wood, so that soon a draught was established up the chimney, and the smoke was

(1) This idea has been so prevalent in France, almost up to the present time, that a very few years ago, on the occasion of the English Ambassador at Paris giving a grand entertainment, no ladies attended in consequence of a report that his Lordship used coal fires.

effectually discharged into the air. The fireplace used to warm the "Cabinet des Livres" at the Louvre is shown in Figs. 2234, 2235. The hearth was a thick

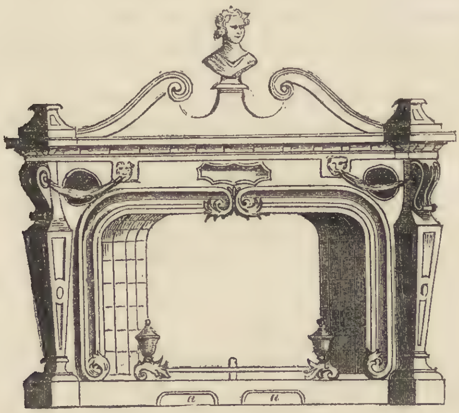


Fig. 2234.

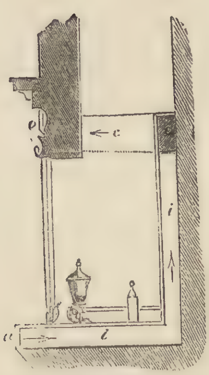


Fig. 2235.

iron plate placed above the old hearth with an interval *i* of 3 inches between. The two sides or *covings* of the fireplace were also formed of thick iron plates, placed 3 inches from the jambs. The space *i* at the back and the spaces at the sides communicated with the interval *i* under the hearth. Two pipes or channels *c* opened from these hollow spaces into the room at *o*, which spaces could be closed at pleasure. When the fire was burning, the iron hearth and the plates which formed the sides and the back became heated. The cold air, entering at the lower openings *a a* at the floor, into the space *i*, became heated by the hearth, and rising into the spaces at the back and sides, was further raised in temperature; it then entered the channels *c*, escaped at *o*, and became diffused through the room.

Savot also describes a plan for heating 2 adjacent rooms by means of one fire. The fireplaces of the 2 rooms are separated by a plate of iron, as shown in Fig. 2236; and a fire being made on one hearth of one fireplace heats the plate, and this, by radiating its heat, warms the air of the other room, the flue of which is closed. If the second room have no chimney, it may still be warmed by making an opening in the wall at the back of the fire of the first room, and closing it with an iron plate.

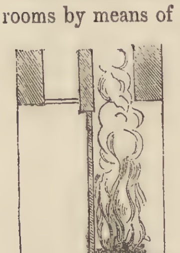


Fig. 2236.

In the year 1713 the Cardinal Polignac published, under an assumed name, a treatise on the art of warming rooms, which deserves especial notice.[1] In his preface he thus concisely states his method of warming. "A plate of iron or copper bowed or bended after such a manner as is not at all disagreeable to the sight; a void behind, divided by certain small iron bands or partition plates, forming several spaces that have a communication one with another; a little vent hole in the middle of the hearth, a register plate in the upper part of the funnel, and, for some shafts, a capital on the top, make up the whole construction and workmanship of our modern chimney. To be able to kindle a fire speedily, and make it, if you please, flame continually, whatever wood is burning, without the use of bellows; to give heat to a spacious room, and even to another adjoining, with a little fire; to warm one's self at the same time on all sides, be the weather ever so cold, without scorching; to breathe a pure air always fresh, and to such a degree of warmth as is thought fit; to be never annoyed with smoke in one's apartment, nor have any moisture therein; to quench by one's self, and in an instant, any fire that may catch in the tunnel of a chimney; all these are but a few of the effects and properties of these wonderful machines, notwithstanding their apparent simplicity. Since I used this sort of chimney, I have not been troubled one moment with smoke, in a lodging which it rendered before untenable as soon as a fire was lighted; I have always inhaled, even during the sharpest seasons, a fresh air like that of the spring. In 1709, water that froze hard everywhere else very near the hearth, did not congeal at night in my chamber, though the fire was put out before midnight; and all that was brought thither in the day soon thawed; neither did I ever perceive the least moisture in winter, not even during thaws."

Although this treatise was written 150 years ago, the opening remarks are still applicable, coal being substituted for wood. The author says:—"It seems that those who have hitherto built or caused chimneys to be erected, have only taken care to contrive in the chambers certain places where wood may be burnt, without making a due reflection that the wood in burning ought to warm those chambers, and the persons who are in them; at least, it is certain that but a very little heat is felt of the fire made in the ordinary chimneys, and that they might be ordered so as to send forth a great deal more, only by changing the disposition of their jambs and wings." The methods by which a fire may communicate its heating effect to a room, are correctly stated to be by *radiation*, by *reflection*, and by *conduction*. Now as radiant heat is reflected according to the same law as light, *i.e.* the angle of incidence is equal to the angle of reflection, it follows that, in a fireplace with straight jambs, very few of the rays are reflected into the

(1) This treatise, published under the name of Gauger, is entitled, "La Méchanique du Feu, ou l'Art d'en augmenter les effets, et d'en diminuer la dépense; contenant le Traité de Nouvelles Cheminées, qui échauffent plus que les Cheminées ordinaires, et qui ne sont point sujettes à fumer." This treatise was reprinted at Amsterdam, in 1714, and a translation of it by Dr. Desaguliers appeared in London, in 1716.

room. Thus, suppose a fire, *f*, Fig. 2237, to be made in an ordinary chimney, A B, *b a*, of which the jambs, A B, *b a*, are parallel, the ray of heat, *f* G, will be reflected back in M; the ray *f* H upon itself in *f;* the ray *f* I in N; and the ray *f* L in P; and this is the only ray that can be reflected into the chamber, the others being to the back, or up the chimney, or among the fuel, and contribute in no way to the useful heating effect of the fire. In cases, however, where the jambs are formed of plaster, there is not even this reflection, for the heat, falling upon the dull surface, is absorbed. The author then describes what ought to be the correct form of the jambs:—"Geometricians," he says, "are sensible that all radiuses which set out from the focus of a parabola and fall upon its sides, are reflected back parallel to its axis. If, therefore, you take on the bottom of a chimney hearth, A B, *b a*, Fig. 2238, a length, *c* C, equal to that of the wood designed to be burnt, for example, of half a log or billet, which, at Paris, is 22 inches; from the points C *c*, let fall the perpendicular C D, *c d*, which may be the axis of two semi-parabolas, whereof C *c* are the vertices and A *a* (the distance between which is the breadth of the chimney) each of them one of their points; that done, you are to line with iron or copper plates the two parabolical sides A C, *a c*, of the chimney, and make the lower part of the concave parallel to the horizon, and as large as it can be, only leaving 10 or 12 inches for the aperture of the chimney funnel. By this arrangement, as much of the heat as can be will be reflected, for all the rays of heat from the focus F *f* of each semi-parabola, as *f g*, *f h*, *f i*, *f l*, &c., will be reflected back parallel to the axis *c d* in *m*, *n*, *o*, *p*, and consequently, pass into the room. So also, all those rays, E H I, which are not reflected back parallel to the axis, will nevertheless be reflected into the chamber or very nearly so. Besides this, the jambs being so much nearer the fire than is usual, will soon become heated, and reflect a larger number of rays."

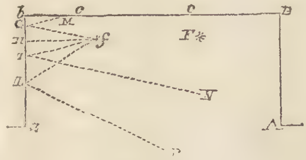


Fig. 2237.

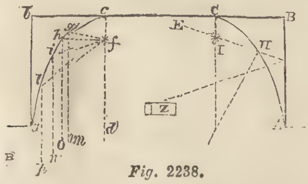


Fig. 2238.

All draughts in the room towards the fire were avoided, by introducing a *soufflet*, or blower, noticed in Savot's stoves, Fig. 2234. Its opening was situated at Z, Fig. 2238, in the centre of the hearth, 10 or 12 inches below the plate on which the fuel was burned, and communicated with the open air by a channel from 4 to 6 inches square. The opening in the hearth was furnished with a metal frame, on which was hinged a trap door, or valve, opening upwards; the upper surface of this valve was furnished with a button, which could be grasped with the tongs, and a small bolt beneath could then be drawn back, or closed with the button with which it was connected. The sides of the valve were formed by two thin sectors of iron, which guided the current of air through the channel, and confined it within narrow limits. Two springs in the frame pressed against the sector sides, and kept the valve open at any desired angle; of course, when the valve was shut and bolted, there was no current.

A number of fireplaces are described in this treatise, all of which are furnished with parabolic jambs and the soufflet; but the back, the jambs, the hearth, and the mantel, are also made hollow, for the purpose of pouring a copious supply of heated air into the apartment. These hollow spaces, named *caliducts* or *meanders*, are in one arrangement, Fig. 2239, formed by perpendicular divisions. In another variety, Fig. 2240, they are horizontal. Here the hearth is also hollowed out and divided into a series of square spaces. The cold air entering at *a*, follows the direction of the arrows, and escapes into the room at *n; h* is the hearth, *s* the smoke flue, and *m m' m''* the caliducts. The supply of hot air into the room was regulated by a valve in the air channel, formed on the principle of the four-way cock. [See STEAM ENGINE, Fig. 2041.] A small cylinder, *c c*, Fig. 2241, moved within another fixed cylinder. The revolving cylinder had 2 apertures, *o o*, and the fixed cylinder 3 apertures. The axis of the revolving cylinder passed through the cover of the fixed cylinder, and had a small lever or needle attached to it, by means of which the cylinder was turned by the hand into certain positions marked on a small dial. When the apertures, *o o*, in the revolving cylinder coincided with those in the fixed cylinder, the external air from the channel was admitted into the caliducts in the chimney back: by turning the revolving cylinder into another position, the cold air was excluded from the caliducts, and admitted directly into the apartments. The cylinder could also be placed so as to shut off the cold air both from the caliducts and from the room. In this way the air of the room could be tempered according to the wants and feelings of the occupants.

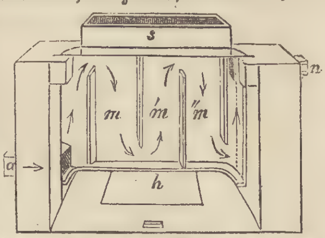


Fig. 2239.

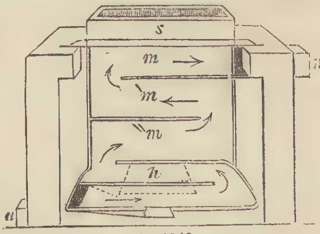


Fig. 2240.

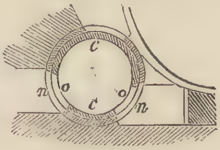


Fig. 2241.

The arrangement which the Cardinal preferred is represented in the following figures. Fig. 2242 re-

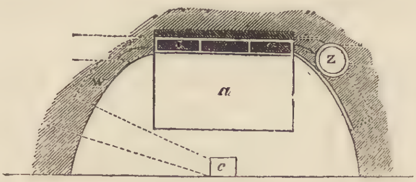


Fig. 2242.

presents a horizontal section of the fireplace, and Fig. 2243, a vertical section. The hollow metal case forming the back of the chimney is divided into 3 or more caliducts, *p q r*, each 4 inches wide and 6¾ inches broad, placed about an inch from the back wall of the hearth recess, with its lower edge, *m*, about 2 inches above the surface of the iron bottom plate or hearth, *a*. The jambs, w, lined with iron or brass plates, are formed in a parabolic curve, and solid at the back. The channel *x*, conducting the external air into

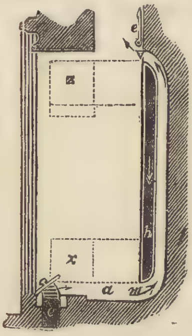


Fig. 2243.

the caliducts, is 9 inches on the side; and the blower *c*, furnished with its valve, forms an aperture 3 inches long and 2½ wide, but instead of being supplied with air from the outside by a separate channel, the air is derived from the channel *z*. The air-valve *x* is placed at the junction of the cold air channel with the caliducts; and the aperture *z*, through which the warmed air enters the room, is fitted with a sliding valve, to close the warm air aperture. The action of this apparatus is as follows:—The small wood on the hearth being lighted, and the valve of the soufflet *c* lifted up, the logs soon begin to kindle into a good fire; the smoke and flame rise into the space between the back, *p q r*, and the wall of the hearth, and, after heating the iron back of the caliducts, escape into the flue. In the meantime, the other face towards the room is also quickly heated by the flame and smoke. The valve being adjusted to admit the external air into the first caliduct, it flows thence into the second and third caliducts, receiving fresh accessions of heat in its progress, until it escapes at *z*, into the apartment, which it speedily warms.

For large apartments, these fireplaces may be erected in the middle of the room, and two may be set back to back, with one series of caliducts for both, so that the air will be heated, whether the fire be kindled in one or both. When kindled in both, the heating effect will, of course, be greatly increased. So, also, two adjoining rooms may be heated by one fire, provided the hearth recesses are placed back to back; for, by making a fire in one room, the heated air from the caliducts may be discharged into the other; or by carrying a pipe from the caliducts through the wall into an adjoining room, or through the ceiling into an upper room, an agreeable and a sufficient warmth may be distributed.

Subsequent writers of repute have acknowledged the great merits of the Cardinal's treatise. Franklin admitted the great assistance it had afforded him; and the improvements in stoves, introduced by Count Rumford, are similar in principle to those suggested by this book. The Polignac fireplaces were constructed for wood fuel. Dr. Desaguliers modified them so as to admit of coal being used in them, and they were getting into general use in England, when an outcry was raised that "they burnt the air," and they fell into disfavour.

The chief improvement introduced by Count Rumford (whose stove has popularised his name,) was to contract the area of the fire-chamber, and to place a flat surface in each interior angle, as shown in the plan, Fig. 2244, so as to

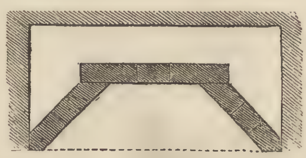


Fig. 2244.

reflect into the room that portion of heat which in the old square grates escaped up the chimney. The throat of the chimney was also much diminished in size, and the breast *b*, Fig. 2245, rounded off so as to allow the smoke to ascend more readily. When the chimney was to be swept the plate or flagstone *p* was removed so as to widen the throat. To obtain the most effect from the fuel, Rumford recommended that the sides of the fireplace be fixed at an angle of 135° with the back of the grate, or at an angle of 45° with a line drawn across the front of the fireplace,

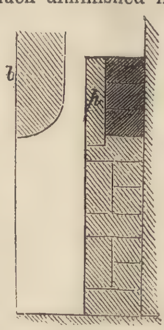


Fig. 2245.

such as the dotted line in Fig. 2244. These angular covings are to be of some badly conducting material, such as fire-clay polished with lampblack. Circular covings are objected to on the ground that they produce eddies or currents which would interfere with the free ascent of the smoke; and Rumford also objected to the old form of registers or metal covers for a similar reason, and also because by sloping upwards towards the back of the fireplace they caused the warm air from the room to be drawn up the chimney, and thus interfered with the passage of the smoke. These registers were afterwards altered so as to be lower at the back than at the front of the stove; but they should be brought down lower than they are usually placed, and be at an angle of 45°, in which case much of the heat would be reflected into the room. Rumford also greatly diminished the size of the grate, and he considered the best proportions for the chimney recess to be attained when the width of the back was equal to the depth from front to back, and the width of the front or opening between the jambs 3 times the width of the back.

The best form of register stove of moderate size for

diffusing the heat into the room is shown in Fig. 2246. The sides A B, B C, form a right angle, and the bars b b' describe a quadrant of a circle of which the radius is half the length of A B. If Rumford's rule of making the back $\frac{1}{3}$d the width of the front is to be followed, take $\frac{1}{3}$d of A B, which will be B a, and draw a c parallel to A C. In this way the sides of the stove form an angle of 135° with the back, and all the rays of heat which impinge on these sloping sides are reflected into the room in front of the stove in right lines. The falling cover or register top should also form an angle of 135° with the back, and will thus send heat down into the room.

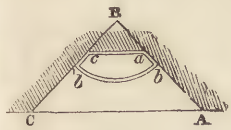


Fig. 2246.

It has been calculated that the waste of fuel in the open fireplace with square jambs is about $\frac{7}{8}$ths, or according to Rumford $\frac{14}{15}$ths. A loss of more than half the heat is said to be carried off in the smoke; about $\frac{3}{8}$ths of the heat is carried up the chimney by the current of air which enters the chimney between the fire and the mantlepiece. The soot is estimated at $\frac{1}{8}$th of the fuel; so that $\frac{3}{8}$ths being carried off in smoke; $\frac{3}{8}$ds in the warm air of the room carried up the chimney, and $\frac{1}{8}$th lost in soot, there is a total loss of $\frac{7}{8}$ths of the fuel consumed or of the heat produced. An open fire also produces very unequal heating effects at different distances; it engenders cold draughts from doors and windows; a cold foot bath to the feet; deficient ventilation; smoke and dust; loss of time in lighting fires, and danger to property and to the person.

2. *The close stove.* In places where fuel is scarce the close stove is used. Fig. 2247 represents the *Dutch*, or simplest form of stove. Near the bottom is a grate for the fuel, which is introduced by the door above; the lower door opens into the ash-pit, and by opening this more or less the draught can be regulated, for the air which feeds the fire must pass up through it: thus the whole body of the stove, which is of iron, soon becomes very hot, and by extending the sheet-iron flue pipe to a considerable length in the space to be heated, the products of combustion are made subservient to the general heating effect on their way to the chimney. It must, however, be admitted that the air of a room heated in this way acquires a burnt, and often sulphurous smell, and becomes negatively electrical; it becomes also very dry, and shrivels up organic substances. Persons habitually breathing such air are subject to headaches, giddiness, and other unpleasant symptoms. This stove is, however, useful to laundresses and others who employ it for heating irons or for drying. It is made of an ornamental form for halls, &c., and when furnished with a vase for containing water its use is less objectionable.

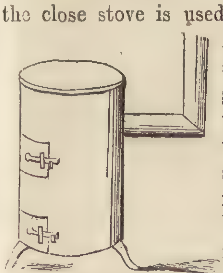


Fig. 2247.

The flue, however, is apt to become overneated, and thus lead to danger.

What is called the *American stove*, Fig. 2248, consists of a square, close, iron box, mounted on short iron legs, with a vessel of water on it to keep the air moist. Beneath the door is a projecting plate: wood fuel introduced at the door is burned, and the flame passing along in the direction of the arrows to the chimney, heats an inner box or oven, the door of which is at the side. Within the large door is a smaller door for regulating the draught.

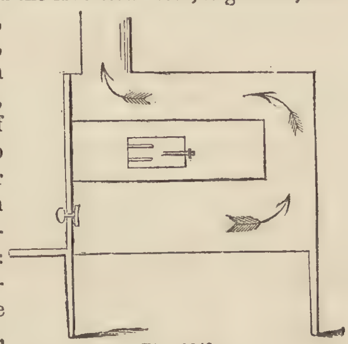


Fig. 2248.

In the north of Europe the stove is constructed with a view to the economy of fuel, while the heating effect is considerable. The fuel in the fireplace is surrounded by fire-stone, bricks or other bad conductors of heat; the air admitted to the fuel is regulated by valves in the doors which enclose the ash-pit and fire-chamber, both doors and valves fitting accurately: the gaseous products of combustion in escaping from the fuel are brought into contact with a meandering flue formed of glazed tiles, and presenting a large amount of surface to the air of the room which is to be warmed: the smoke is admitted into the chimney with as small a velocity or at as low a temperature (not exceeding 150°) as is consistent with the maintaining of a high temperature in the fireplace. The general form of stove adapted to these conditions is shown in Fig. 2249. It consists of a quadrangular box A B C D, the size of which in the directions A C, B D, is adapted to the space to be heated; but the inside width from front to back is not less than 10 inches, and seldom exceeds 20. The whole included space is divided by means of partitions. The lowest chamber F contains the fuel: this is placed on the bottom of the stove, which does not contain a grate. d is the door of the fireplace, and in it is a small wicket w. The roof of the fireplace extends to within a few inches of the further end, there being only a narrow passage F for the flame. At the distance of about 8 inches above the partition F¹, is a second partition 2, 2, extending nearly to the other side A C, leaving only a narrow passage for the flame. The partitions 3, 4, 5 and 6 occur at intervals of 8 inches, with passages at the ends alternately disposed, the last communicating with the vent in the flue f,

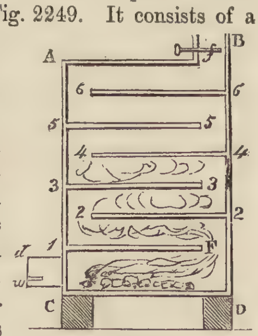


Fig. 2249.

the draught being regulated by an iron plate or damper stretching across *f*. If the fuel be of wood, as it usually is, and the vent is situated in the room while the fireplace is in an outer lobby, the vent is closed by a sort of pan or earthenware bowl inverted over it, with its brim buried in sand contained in a groove formed round the hole. The stove is usually situated in a corner of the room so arranged that the chimneys can be joined in stacks. In lighting the stove, shavings or straw may be first burnt at the further end of the hearth, so as to warm the air in the stove and determine a current. The fuel is piled up on the hearth close to the door and kindled, and the current being already directed to the vent, there is no escape of smoke from the door *d*. This door is now closed and the wicket *w* opened, by which a narrow stream or jet of air is directed to the base of the heaped up fuel, which thus soon enters into brisk combustion.

It will be evident that in the construction of this stove the flame and heated products of combustion are retained as long as possible within the body of the stove, and the heat diffused over a very extended surface, which is further increased by making the stove narrower from front to back in its upper part. A greater breadth is required below on account of the bulky wood fuel; but if this breadth were maintained all the way up, heat would be lost in warming the partitions; but by diminishing the breadth of these, the proportion of heating surface is increased. The whole body of the stove is like a long pipe folded up; and the effect would be increased if each partition were split into two, and a free passage allowed between them for the air of the room. To maintain as large an extent of heated surface as possible the stove is detached from the wall, and raised from the floor on short pillars C D, so that both the back and the bottom of the stove are sources of heat to the air of the room. In some cases, however, the stove forms a portion of the wall which separates two rooms, and serves to warm both; but the door of the fire is usually in the lobby, so that the servant can manage the fire without entering the room.

In the best houses, these stoves are described as being "built in tower-like shapes, story over story of pure white porcelain, in various graceful architectural mouldings; sometimes surmounted with classic figures of great beauty, and opening with brass doors, kept as bright as if they were of gold. In houses of less display, these stoves are merely a projection in the wall, coloured and corniced in the same style as the apartment. In adjoining rooms they are generally placed back to back, so that the same fire suffices for both. These are heated but once in the twenty-four hours by an old Caliban, whose business during the winter it is to do little else. Each stove will hold a heavy armful of billet, which blazes, snaps, and cracks most merrily; and when the ashes have been carefully turned and raked with what is termed an *ofen gabel*, or stove fork, so that no unburnt morsel remains, the chimney aperture is closed over the glowing embers, the brass doors firmly shut, and in about six hours after this, the stove is at the hottest—indeed, it never cools." [1] There is no doubt that with this stove there is much heating effect, and great economy of fuel; but these results are attained at so great a cost as the sacrifice of ventilation. Every precaution is taken to prevent the air of the room from being changed; the windows are made to fit as tight as possible, and any cracks or chinks that might admit a breath of cold air are pasted over with paper; double windows are common, and doors are made to close accurately. Hence, the occupants of the rooms inhale a warm but very corrupt air, which must act injuriously on the health.

The stove, Fig. 2249, although the same in principle as the *Russian* or *German*, referred to in the above quotation, belongs rather to the variety known as the *Swedish stove*. In the Russian or German stove, the smoke and products of combustion in escaping to the chimney, part with their heat to the sides of the ponderous flue of glazed tiles, built in several stories in the room which is to be heated. In the Swedish stove the smoke is exposed to a high temperature by the heating of the partitions, so that every particle of soot is consumed. The Swedish stoves have from 4 to 9 channels for the circulation of the smoke, and some of the channels are fitted with ovens, (as in the American stove, Fig. 2248), others are contrived for the reception of one or more boilers.

A great variety of stoves with ascending or descending flues have been contrived at various times: our limited space will not allow us to do more than give one or two further examples. Fig. 2250 represents a section of a stove with a descending current. The cover to the stove has an opening at O; *f* is the fire chamber, with the grating; below this, is a space S, with a second grating; *a*, is the ash-pit, containing a drawer for the ashes; F F′ are horizontal flues on each side of the ash-box, communicating with vertical flues which lead into the chimney. The whole arrangement is contained in a niche formed by closing up the fireplace. In lighting the fire, the direction of the draught should be ascertained by holding a flame over the opening O, and if it be drawn downwards, the fire is lighted by first putting charcoal on the grate, placing wood on the charcoal, and paper on the wood. The paper is now to be lighted, and the cover to O shut, when air will pass through the airholes of the cover and cause the ignition of the materials. The flame and hot air descending through the grating at *f*, a current will pass down, dividing when it reaches S, so as to pass into the horizontal channels F F′, and from thence into the vertical flue, and so to the chimney. The surfaces of the vase and air-box, and those portions of

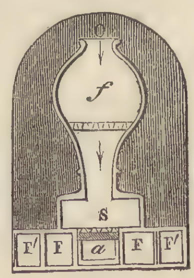


Fig. 2250.

(1) "Residence on the Shores of the Baltic." 1841.

the horizontal channels which are exposed to the room, are heated by the hot descending current, and the air of the room is thus warmed. The success of this stove depends on maintaining a steady upward draught in the chimney flue, so that the ash-pit drawer, and a door in the chamber s, used for removing cinders &c. from the second grate, must be air tight. In lighting the fire an upward current may be determined by holding a flame in a small door in the side of the flue.

Dr. Arnott's stove has excited a good deal of attention of late years. Its action depends on allowing the fuel to burn very slowly, the admission of air being regulated by a peculiar contrivance. Fig. 2251 represents a section of one of these stoves, in which a box of sheet iron, *a b c d*, is divided by the partition *g h*, into two chambers, which communicate freely at the top and bottom; *e* is the fire-box of iron, lined with fire-brick, and resting on a close ash-pit with a door at *b*, near which is a valved opening, by which air enters to feed the fire when the door is shut; *i* is the door of the stove by which fuel is introduced; *c* is the chimney flue. When the ash-pit door and the stove-door are shut, the quantity of air admitted by the valved opening in the ash-pit is only just sufficient to support combustion, and only a small corresponding quantity of air can pass away by the chimney. The whole box then soon becomes filled with hot air, or smoke from the fire circulating in it, and rendering it everywhere of as uniform temperature as if it were full of hot water. This circulation takes place because the air in the front chamber around the fire-box, and which receives as a mixture the red-hot air issuing from the fire, is hotter, and therefore, specifically lighter, than the air in the posterior chamber, which receives no direct heat, but is always losing heat from its sides and back; and thus, as long as the fire is burning, there must be circulation, the whole mass of air revolving in the direction of the arrows. The quantity of new air rising from within the fuel, and the like quantity escaping by the flue *c*, are very small compared to the revolving mass.

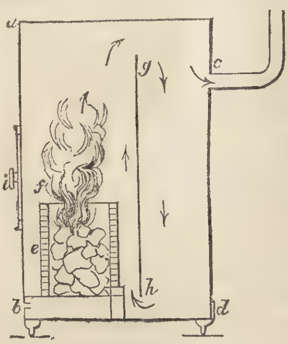


Fig. 2251.

With this stove, Dr. Arnott, during the severe winter of 1836-7, was able to maintain in his library a uniform temperature of from 60° to 63°. The coal used must be anthracite, or such as does not produce smoke in any quantity. Of this coal, six pounds, or less than a pennyworth, suffice for a day's consumption. The grate or fire-box, when fully charged, contains a supply for 26 hours.

There are several ingenious contrivances for admitting the air into this stove, one of which is shown in Fig. 2252, in which *a b c* is a bent tube closed at *a*, where it contains air, and open at *c*. The bent part at *b* contains mercury; from *c* a bent tube proceeds and supplies air to the stove. When the internal heat is great, the air in *a* expands and forces mercury up in *c*, so as to close its mouth and prevent air from entering the stove.

Although the air of the room may be sufficiently warmed by this stove, yet it soon becomes hot and oppressive for want of moisture and ventilation. A pan of water placed on the top of the stove will supply the one, but as far as respects ventilation this stove is defective. 1 lb. of coal requires about 150 cubic feet of air for combustion; but as a portion escapes without being chemically acted on, 200 cubic feet may be allowed. Suppose a room warmed by an Arnott's stove to be 15 feet long, 12 wide, and 11 high, its cubic contents are 1,980 feet, and if 6 lbs. of coal per day be burned, each pound requiring 200 cubic feet, there will be only 1,200 cubic feet used for the combustion; and as this quantity must pass through the stove, and be carried off by the flue, the air of the apartment is not once changed or renewed by the action of the stove in the course of 24 hours. This is a sufficient reason why the apartment is so readily warmed by this stove, and it also accounts for its unpleasant effects on the animal system. We fear also that from the slow combustion of the fuel, carbonic oxide is generated, and that this is liable, from the small draught of the chimney, to escape into the room.

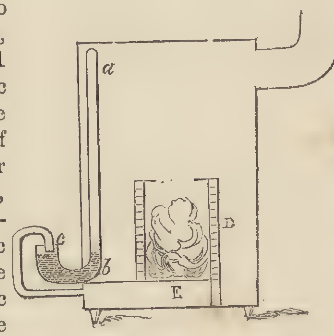


Fig. 2252.

Combustion of smoke.—Some of the stoves above described have the merit of consuming their own smoke. When much smoke is produced, there is an enormous waste of fuel, which contaminates the air, disfigures everything that it touches, fouls the chimney, and sometimes takes fire in the chimney. After Watt had made the steam-engine an economical source of power for so many purposes, the rapid increase in the number of steam-engine and other furnaces led to a great increase of the smoke nuisance. Watt saw the evil, and in 1795 took out a patent for a method of constructing furnaces so as "to cause the smoke or flame of the fresh fuel, in its way to the flues or chimney, to pass together with a current of fresh air, through, over, or among fuel which has already ceased to smoke, or which is converted into coke, charcoal, or cinders, and which is intensely hot; by which means the smoke and grosser parts of the flame by coming into close contact with, or by being brought near unto, the said intensely hot fuel, and by being mixed with the current of fresh or unburned air, are consumed or converted into heat, or into pure flame, free from smoke." There is no doubt that the principle

thus announced is a correct one, and may be carried out by any careful stoker without any special construction of furnace. All that is required is to adopt this precaution: in adding fresh coals they must not be thrown to the back or middle of the furnace among the incandescent fuel, for in such case a dense cloud of black smoke will be produced; but the coals must be in the first instance carefully placed on a dead plate in front of the fire, where they may become gradually heated, in which case the gases which escape from them are carried in with the draught over the incandescent fuel, and undergo combustion; the fuel in this way becomes coked, and in proportion as it does so it may be moved forwards towards the centre of the fire, fresh fuel being added to supply its place behind. The writer has seen a steam-engine furnace fed in this way, which emitted little or no smoke from the chimney shaft; but in order to produce such a result the stoker must be an intelligent, unprejudiced man, and it is difficult to find a poor man engaged in any pursuit without strong prejudices in favour of his own way of doing things; and in the case of stoking, the usual plan is to shovel on the coals every 20 or 30 minutes as quickly as possible, throwing them with a vigorous arm to the back of the furnace. The stoker then has leisure to smoke his pipe or to go to sleep until a fresh supply of coals is wanted. Now the former plan calls for frequent attention, care, and judgment on the part of the stoker, which qualities being rare, attempts have been made to supply them by machinery. One of the best forms for this purpose is *Jucke's patent furnace.* The following is a description of one in actual use in Truman's brewery, which we prefer to a general description on account of the statement of the actual saving of fuel which accompanies it. Jucke's furnace "consists of a strong cast-iron frame of the full width of the furnace, and about 3 feet longer. The fire-bars are all connected together, forming, when complete, an endless chain, and are made to revolve round a drum, placed at each end of the frame. The front of the frame is provided with a hopper, in which the fuel is placed, and a furnace-door, which opens vertically, with a worm and pinion. The height to which this door is raised by the stoker regulates the supply of coal, which is carried into the fire by the gradual motion of the bars. The whole machine is placed upon wheels, to facilitate its removal for repairs to the boiler, brick-work, or furnace. The speed of the furnace-bars is determined by the draught. It varies from 1½ inch to 3 inches per minute, the object being to keep the whole of the bars covered with fuel, with a small accumulation of fire at the bridge. The bridge is suspended by a pipe, 3 or 4 inches in diameter, fixed about 1 inch above the level of the bars; this allows the clinkers formed to fall into the ash-pit, but will not allow the fire to pass. A small stream of water must be supplied to the pipe or stop, or it will soon be destroyed. All the air admitted to the fire to support combustion is made to pass through the furnace-bars." Messrs. Truman first applied this apparatus to a cylindrical engine-boiler with 2 tubes, driving a 40-horse engine, and it was afterwards applied to a brewing copper. "But with a brewing copper provision has to be made for a process in the manufacture almost peculiar to it: the contents of the copper have to be turned out several times in the course of a brewing, rendering it necessary to 'bank-up' the fire thoroughly to protect the bottom of the copper until refilled with wort or water. It was feared that the machinery would interfere with this being done effectually: it was tried, and with the same success as with the steam-boilers. It was found that a fire of 50 or 60 feet area could be worked for any number of hours without the slightest appearance of smoke from the chimney shaft; but the process of banking-up required the whole principle of the machine to be put in abeyance, during which time smoke escapes from the shaft, sometimes in large quantities, and no plan has been discovered for its prevention." The apparatus was applied to 14 furnaces, at a cost, including brick-work, of about 3,000*l.* The consumption of coals in the brewery is about 6,000 tons per annum. The saving in the coal account since the introduction of the patent furnaces has been as follows:—

	£	s.	d.
July 1, 1848	69	4	0
" 1849	631	4	0
" 1850	1,606	0	0
" 1851	1,925	12	0
" 1852	1,906	0	0
" 1853	2,200	0	0
	£8,338	0	0

from which sum is to be deducted for casualties and sundries about 350*l.* "The above economy has not arisen from less weight of fuel consumed, but owing to the screenings or dust of coal only being required for the furnaces." [1] Mr. George Wilson has used three forms of apparatus, patented by Jucke, Hazeldine, and Hall, respectively. They act on the same principle: "a very small continuous supply of fuel at the front of the grate, the smoke always being made in small quantities, combines with the air that passes through the bars, and is burnt before it can escape. All three have the advantage that there is no opening of fire-doors, and therefore an avoidance of the rush of cold air, which must have an injurious effect by contracting the boiler-plates, in addition to the loss of heat. The only comparison we have to give of smoke-consumers with old-fashioned furnaces, is, that our smoke-consumers do as much work with small coal as the old furnaces did with large. We tried a smoke-consumer, firing and stoking as in common furnaces, and found the coal used to be 12 per cent. more than when the grate was used as a smoke-consumer."

Accepting the common definition of smoke as unconsumed fuel in a state of minute division, or that

(1) The above details are from a paper by Mr. A. Fraser, "On the Consumption of Smoke," read before the Society of Arts, London, 30th November, 1853, and printed in the Society's Journal, No. 54, together with a notice of the discussion which took place thereon. In No. 57 is an account of a further discussion on the subject. In vol. i. of the Society's Journal, p. 626, is an interesting letter from Mr. George Wilson, recording his experience with smoke-consuming apparatus at Price's factory at Belmont and at Battersea.

"smoke consists essentially of carbon, separated by heat from coal or other substances, and is commonly mixed with carbonic acid gas, carbonic oxide, and other matters," we may just glance at the principle of the various other contrivances that have been invented to get rid of it. It is, however, preferred in many furnaces to use coke or anthracite, so as not to produce any smoke. But where bituminous coal is used, the compounds of carbon and hydrogen, which are distilled off by the heat, do not undergo combustion, on account of the deficient supply of air to the furnace; there may be sufficient heat to decompose them, and thus increase the quantity of minutely divided carbon or visible smoke; but for want of oxygen they escape with the draught into the chimney, and so are discharged into the air. Hence, if an additional quantity of air be thrown into the fire so as to produce perfect combustion of the carbonaceous matter, not only would more heat be produced from a given quantity of fuel, but no smoke would escape. Many plans have been contrived for admitting air to the fuel; in some cases it was warmed before it came in contact with the hot vapours; in others it was admitted in the form of numerous jets; others, again, allowed it to pass in at the ordinary temperature through sliding doors and regulators, in which case the consumption of fuel was increased. Another plan was to supply the fire with fuel in small quantities, "much scattered and divided, so that the coal was not only ignited as it fell upon the fire, but the heated vapours at the same time had a supply of air sufficient to produce their complete combustion. To some extent this might be effected by the careful stoking of a skilful fireman in a well-constructed furnace: but as this constant attention to the supply and frequent stoking of the burning coals involved often repeated openings of the fire-doors, and the consequent admission of cold air in excess, mechanical contrivances had been introduced which, without opening the fire-doors (until it became necessary to raise the fire from the grate-bars, and to clear them from the *clinkers*, or earthy parts of the coal vitrified by the heat), scattered a constant and continuous supply of fuel upon the fire. In most of these devices there was a hopper filled with coal, and a pair of rollers through which it passed. It then either fell directly on the fire, as in Brunton's revolving grate, or it was scattered over the fire by the centrifrugal action of fans or wings fixed upon the surface of two very flat cones, upon which the coal dropped from the rollers, as in Mr. Stanley's plan, much used in Manchester, where the governor of the steam-engine regulated also the supply of fuel to the furnace, according the engine's demand for steam." [1] The necessity for raising the fire to remove the clinkers is an objection to this plan, and led to that of giving "a longitudinal motion to the grate, by which it fed itself with coal at the furnace mouth, and cast off the clinkers at the tail-end of the fire-bars, the forward motion corresponding with the consumption of the fuel; while by other motions given to the fire-bars the mass of fire was broken or stoked so as to admit a due supply of air, and the clinkers disengaged from the bars, so as to be readily cast off when they reached the end of the bars." Mr. Jucke's arrangement on this principle has been already noticed. Hall's arrangement consists of a series of bars of the whole length of the fire, moved alternately by an eccentric shaft in front: the motion is very slow, but the effect is to supply the fire with fuel from a hopper in front. In Hazeldine's arrangement the bars are of the width of the fire, transversely with the boiler; a peculiar motion is given by a cam to each bar, by which the fire is supplied with fuel from a hopper, which is opened vertically by a rack and pinion. Mr. Glynn also mentioned a plan by Mr. Godson for supplying furnaces "with coal from below by forcing up a column of fuel, which was lighted at the top, and caked as it was delivered to the furnace, the column of coals being pressed upwards in a box as a candle was raised in the socket of a candlestick, or like the wick of a lamp."

The preceding plans refer to furnace-fires. Not many plans have been proposed for consuming the smoke, and preventing the formation of soot in domestic fires. Dr. Franklin, however, contrived the circular fire-cage, Fig. 2253, which is about a foot in diameter, and from 6 to 8 inches wide from front to back: the back is of plate-iron, and the front contains bars, of which the 3 middle ones are fixed, and the top and bottom bars movable, so that either may be drawn out for the purpose of filling the grate with fuel. The cage turns upon axes, supported by a crotchet fixed on a stem which revolves on a pivot fixed to the hearth. The fire is lighted by withdrawing the upper bar, and placing paper, wood, and coals in the grate: the bar is then replaced. When the fire is first lighted, smoke is produced; but as soon as the fire begins to

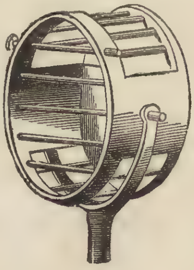


Fig. 2253

(1) From Mr. Glynn's address to the Society of Arts at the adjourned discussion on the consumption of smoke. We may also refer to the Report of the Parliamentary Committee of the years 1819 and 1820, "to inquire how far it may be practicable to compel persons using steam-engines and furnaces in their different works, to erect them in a manner less prejudicial to public health and public comfort." This Report contains a large number of plans for preventing or consuming smoke, the principles of which are given above, and some of them must have impressed the Committee with their efficiency, (as indeed they are efficient if properly carried out,) for they state in their Report that a means of destroying smoke "had been satisfactorily and effectually obtained." The abundance of fuel and the absence of skilled labour in its application, have caused the whole subject to be nearly forgotten, although a second Parliamentary Committee heard evidence and reported thereon in 1843; and it was not until the session of 1853, when an Act was passed, requiring manufacturers and others using furnaces to consume their smoke, that means are now being adopted for carrying into effect a process which was successfully applied by Franklin and Watt in the last century, and has been presented to the public in the middle of the present century, with much of the inexperience which accompanies new and untried schemes.

burn well the cage is turned round on its axes, so that the incandescent coals at the bottom shall be uppermost; the whole is then turned round on the pivot, so as to bring the bars again in front, by which arrangement the fresh coals will be below the ignited fuel, and these gradually kindling, their smoke will pass through the fire above them and be consumed. On adding fresh fuel the top bar is removed, then replaced, and the cage turned over and round as before. The cage can of course be turned round upon its vertical axis, so as to radiate its heat in any direction, and by placing the bars in a horizonal position a kettle may be boiled on them.

In Section III., a warming, and ventilating, and smoke consuming stove will be described.

3. *The cockle stove.*[1]—This is a contrivance for heating a large body of air. The cockle or fire-chamber, *c*, Fig. 2254, is cylindrical in form, with a flat or dome-shaped head, and a pipe leads from near the upper part to carry off the smoke into the flue. The cockle is placed on a bed of masonry or brick-work, with a grating *b* for the fire,

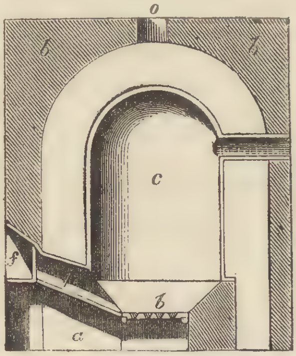


Fig. 2254.

and an ash-pit *a*, beneath, as in Figs. 2254, 2255. The fuel is supplied at the door *f*, and passes down a sloping dead-plate *p* to the grate. The ash-pit and draught-hole are shown at *a*. Surrounding the cockle at a certain distance, and concentric therewith, is a mass of brick-work *b b* forming a space for the air, which is to be heated, and which is supplied from the passages below or from the external air. The

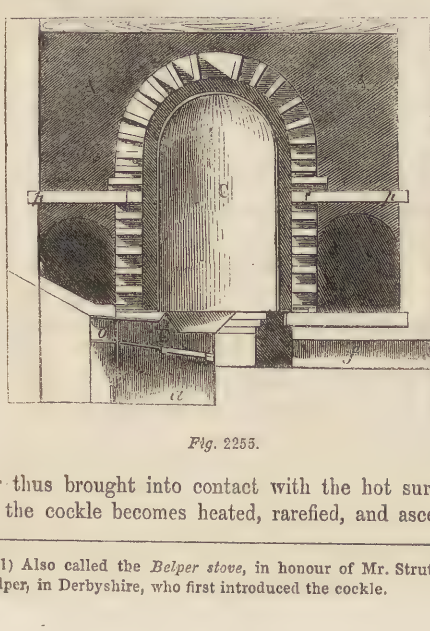


Fig. 2255.

air thus brought into contact with the hot surface of the cockle becomes heated, rarefied, and ascends and passes out through one or more apertures *o* into the room which is to be warmed. The cockle may be varied in form so as to present a larger heated surface to the air. Fig. 2255 shows the arrangement of this stove in the Derby Infirmary. The stove should be erected as near the area of the building as may be convenient, and be situated from 6 to 12 feet below the floor, to make the distribution of warm air tolerably uniform. The cockle c, Fig. 2255, is cubical in form, with a domed or groined arch top; it is about 3 feet in diameter and 4 feet high, and is made of iron plates riveted together. The smoke passes off by a narrow passage at the base of the cockle through the flue *f.* The brickwork surrounding the cockle is built with alternate openings between the bricks, at about 8 inches distant from the sides of the cockle, and in these apertures are placed pipes of sheet iron, or common glazed ware, passing to within an inch of the cockle, by which means the air to be heated may be thrown near, or in immediate contact, with the surface of the cockle, if desirable. The horizontal partition *p* cuts off the communication between the lower and the upper portion of the air-chamber, the arched openings in the lower half being the openings of the main air-flue leading from the exterior atmosphere. The fire-room and ash-pit are at *a*, and the fuel is introduced by the opening at *o*. In this arrangement, the air passing from the lower arched flues, through the apertures beneath the horizontal partition, comes into immediate contact with the surface of the cockle, and finds its way into the upper air-chamber, A A, through the numerous pipes or openings of the upper division, by which circuit its velocity is sufficiently retarded to acquire the necessary elevation of temperature from the heated cockle. To prevent the air from being burnt, the size of the fire-chamber must be regulated so as not to raise the cockle to a higher average temperature than 300°. The Derby stove allows the passage of nearly 5 cubic feet of air per second, which is raised to about 130°, when it escapes from the upper air-chamber into the pipes leading to different parts of the building. These pipes are furnished with dampers to regulate the admission of the warm air. If care be taken to prevent the air from being burned, this method of heating a large building has its advantages. It would scarcely answer on a small scale, on account of the expense of erection; nor could it be well applied to a large building, unless constructed during the erection of the edifice. The air passages being placed several feet below the surface of the ground, allow a portion of cold air to be admitted to the interior of the building during summer, by means of a revolving mouth-piece, or turn-cup, placed at the opening of the air-passage, so as to receive the current of wind at the outer extremity of the passage, and thus convey it to the interior.

4. *By Steam.*—The first application of steam to the warming of rooms, that we are acquainted with, was made by James Watt in 1784, who contrived an apparatus for warming his study, the dimensions of which were 18 feet in length, 14 in width, and 8½ in

(1) Also called the *Belper stove*, in honour of Mr. Strutt, of Belper, in Derbyshire, who first introduced the cockle.

height. The apparatus consisted of a box or heater made of 2 side plates of tinned iron about 3½ feet long by 2½ wide, kept asunder about an inch by means of stays, and closed at the edges by tin strips. This heater was placed on edge near the floor. It was furnished with a cock for letting out the air, and was supplied with steam from a boiler by a pipe entering its lower edge, by which pipe the condensed water returned to the boiler. The steam on being admitted into the box was condensed, and the latent heat of the steam being liberated heated the box, which in its turn radiated heat into the apartment. The experiment, however, does not seem to have been very successful.

Mr. Hoyle, of Halifax, in 1791, patented a method of heating by means of steam pipes. The steam was conveyed by a pipe from the boiler to the highest point which was required to be heated, from which by a gentle declivity the condensed water flowed into the supply cistern of the boiler. The pipes were of copper, and too small to produce much useful effect, and so the plan was pronounced a failure.

In 1799, Mr. Lee, of Manchester, erected a heating apparatus of cast-iron pipes, which also served as supports to the floor. This apparatus was constructed by Boulton and Watt, and is said to have been successful.

It is not economical to warm by this method unless there is a steam-engine on the establishment in daily use for other purposes. The steam pipes may then be supplied from the engine boiler, the dimensions of which may be enlarged at the rate of one cubic foot for every 2,000 cubic feet of space, to be heated to the temperature of 70° or 80°. A boiler adapted to an engine of one-horse power, is sufficient for warming 50,000 cubic feet of space. Hence an apparatus erected for the purpose is not required to be of very large size, nor is the quantity of fuel consumed great. It is stated that if the fire under a small boiler be carefully managed, 14 lbs. of Newcastle coal will convert one cubic foot of water at 50°, into 1,800 cubic feet of steam at 216°; and only 12lbs. of coal are required to convert the same quantity of water into steam at 212°. The shape of the boiler, and the method of setting it, are of importance, and the furnace must be arranged so as to admit no more air than is required to support the combustion. The hot air must also be kept in contact with the sides of the boiler, until as much of the heat as possible be abstracted from it. In such an arrangement, according to Dr. Arnott,[1] nearly half of all the heat produced in the combustion is applied to use.

The expenditure of the heat produced is, 1. Through the thin glass of the windows; 2. More slowly through the walls, floors, and ceiling; and 3. In combination with the air which escapes at the joinings of the windows and doors, or through openings expressly made for the purpose of ventilation. The amount of heat lost in this way has been variously estimated by Tredgold and other writers, but Dr. Arnott states it thus:—That in a winter day, with the external temperature at 10° below freezing, to maintain in an ordinary apartment the agreeable and healthful temperature of 60°, there must be of surface of steam pipe, or other steam vessel heated to 200° (which is the average surface-temperature of vessels filled with steam of 212°), about 1 foot square for every 6 feet of single glass window of usual thickness; as much for every 120 feet of wall, roof, and ceiling of ordinary material and thickness; and as much for every 6 cubic feet of hot air escaping per minute as ventilation, and replaced by cold air. A window, with the usual accuracy of fitting, allows about 8 feet of air to pass by it in a minute; and there should be for ventilation, at least 3 feet of air per minute for each person in the room. According to this view, the quantity of steam pipe or vessel required under the temperature supposed, for a room 16 feet square by 12 feet high, with two windows, each 7 feet by 3, and with ventilation, by them or otherwise, at the rate of 16 cubic feet per minute, would be—

	Feet.
For 42 square feet of glass (requiring 1 foot for 6) ...	7
,, 1,238 feet of wall floor and ceiling (requiring 1 foot for 120)..	10⅓
,, 16 feet per minute for ventilation (requiring 1 foot for 6)..	2⅔
Total of heating surface required............	20

Which is 20 feet of pipe, 4 inches in diameter, or any other vessel having the same extent of surface, as a box 2 feet high, with square top and bottom of about 18 inches. It may be noticed, that nearly the same quantity of heated surface would suffice for a larger room, provided the quantity of window glass, and of the ventilation, were not greater; for the extent of wall, owing to its slow conducting quality, produces comparatively little effect.

Dr. Arnott also states that a heated surface, as of iron, glass, &c., at temperatures likely to be met with in rooms, if exposed to colder air, gives out heat with rapidity, nearly proportioned to the excess of its temperature above that of the air around it, less than half the heat being given out by radiation, and more than half by contact of the air. Thus, if the external surface of an iron pipe, heated by steam, be 200°, while the air of the room to be warmed by it is at 50°, showing an excess of temperature in the pipe of 140°, such pipe will give out nearly 7 times as much heat in a minute as when its temperature falls to 80°, because the excess is reduced to 20°, or $\frac{1}{7}$ of what it was. Supposing window glass to cool at the same rate as iron plate, one foot of the steam pipe would give out as much heat as would be dissipated from the room into the external air by about 5 feet of window, the outer surface of which was 30° warmer than that air. But as glass both conducts and radiates heat about $\frac{1}{7}$th slower than iron, the external surface of the glass of a window of a room, heated to 60°, would, in an atmosphere of 22°, be under 50°, leaving an excess of less than 30°; and about 6 feet

(1) "Warming and Ventilation, with directions for making the Thermometer Stove, &c." London, 1838.

of glass would be required to dissipate the heat given off by 1 foot of the steam pipe. In double windows, whether of 2 sashes, or of double panes, only half an inch apart in the same sash, the loss of heat is only about $\frac{1}{4}$th of what it is through a single window. It is also known that 1 foot of black or brown iron surface, the iron being of moderate thickness, with 140° excess of temperature, cools in 1 second of time 156 cubic inches of water, 1 degree. From this standard fact, and the law above given, a rough calculation may be made for any other combination of time, surface, excess, and quantity. And it is to be recollected, that the quantity of heat which changes, in any degree, the temperature of a cubic foot of water, produces the same change on 2,850 cubic feet of atmospheric air.

An apparatus represented in Fig. 2256, for warming air by means of steam, has recently been introduced by Messrs. Hamilton and Weems. By means of a fan F, usually situated on the outside of the building, pure air is driven through and between a series of concen-

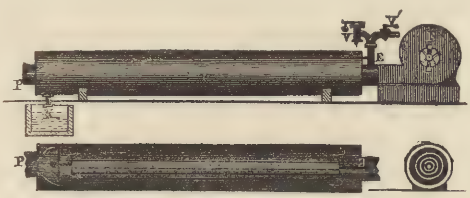


Fig. 2256.

tric annular steam chests C C, and is emitted in a warm state by a pipe P. The steam chests receive steam from the boiler, or in high-pressure engines from its exhaust pipe, which is fitted for the purpose with safety and collapse valves V V′, to regulate the pressure, and a stop-cock to regulate the supply. The condensed steam is carried off by a pipe into a cistern K, and thence back to the boilers The warmed air can be supplied with moisture by allowing a regulated quantity of steam to mix with it in passing through the apparatus.

5. *By hot Water.*—The method of heating by steam pipes has long given way to hot water apparatus. Of this there are two distinct modifications depending on the temperature of the water, and known as the *low pressure* and the *high pressure* systems. In the one case the water is at or below the ordinary temperature of boiling. In the other it is heated to 350° and upwards, so that its tendency is to burst into steam with a pressure of 70 lbs. and upwards on the square inch, and hence it requires to be confined by very strong or high pressure apparatus. In the low pressure system the pipes do not rise to any considerable height above the level of the boiler, so that the apparatus does not require to be of extraordinary strength, either on account of hydrostatic pressure or of temperature. One pipe rises from the top of the boiler, traverses the rooms which are to be warmed, and returns to the boiler, which it enters near the bottom. The pipes heated by the water radiate their heat into the rooms, and the water being cooled in the process has an increasing tendency to descend, just as the tendency of the water in the boiler is to ascend. If the apparatus be properly arranged a constant circulation will thus be maintained through the whole system of pipes, so long as there is a spark of fire under the boiler; and, indeed, so long as there is any marked difference in temperature between one part of the apparatus and another.

The first application, on a large scale, of hot water as a source of heat was made in France, in 1777, by M. Bonnemain, in an apparatus for hatching chickens. This apparatus consisted of a boiler *b*, Fig. 2257, a feed-pipe *f*, and a pipe *h*, (regulated by a stop-cock *o*) by which the hot water ascends from the boiler into the heating pipes. These traverse the chambers

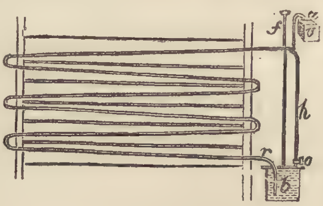


Fig. 2257.

which are to be heated, and are fixed with a gradual slope towards the boiler, to which the water is conveyed by a pipe *r*, which passes nearly to the bottom of the boiler, the velocity of the current depending on the difference between the temperature of the water in the boiler and that in the descending pipe. At the highest point of the apparatus is a pipe *a*, regulated by a stop-cock, for allowing the escape of the air contained in the cold water which is supplied to the boiler, and which becomes liberated by the heat. On opening the stop-cock, there may be a rush of water as well as of air, and a small cistern, *v*, is provided for its reception.

The low pressure system has of late years been greatly improved and largely introduced in consequence of the scientific exertions of Mr. Hood.[1] Fig. 2258 represents an arrangement on his system for warming 3 or 4 floors. In such a case as this, the vertical pipe from the boiler may be carried up to the highest story, and the return pipe be made to diverge into each story on its way to the boiler. In such an arrangement, the top story will be most heated, and the

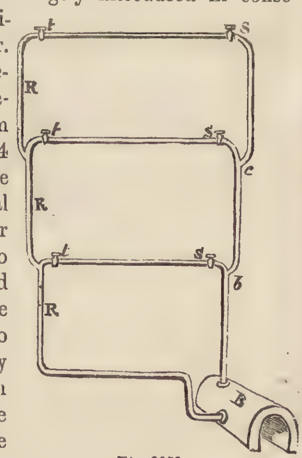


Fig. 2258.

heat will gradually diminish in the lower stories, as water cools in descending. A better arrangement is to supply each story with a separate range of pipes branching out from the main pipe, and returning

(1) The reader who desires to be fully acquainted with the subject of which it treats, will do well to study Mr. Hood's instructive volume, "Practical Treatise on the Warming of Buildings by hot Water," &c. Second Edition, 1844.

together or separately to the boiler. If, however, the branch pipes be simply inserted into the side of the vertical ascending pipe, there is danger of the hot current passing by instead of flowing into them. The motion of the upward current requires to be checked in some way, and this may be done by arranging the pipes as at *b* or *c*, Fig. 2258, at which points it is evident that the water in ascending from the boiler B, receives such an amount of retardation, as to cause it to flow along the horizontal pipe at that level. If it be required to cut off the supply of heat from any one story, all that is necessary is to close the stop-cocks S *t*, in any one horizontal branch, and the hot current will not pass along it.

In some arrangements, a vertical main discharges the hot water into an open cistern at the top of the building, and from this cistern the water is distributed by pipes to various parts of the building. By driving a plug into one of the flow pipes at the bottom of the cistern, any required portion of the building can be cut off from the heating effect.

Of course the boiler must be made sufficiently strong to resist the hydrostatic pressure of the water. A tube of the sectional area of 1 inch, rising from the boiler to the height of 34½ feet, both tube and boiler being full of water, will exert a bursting pressure on every square inch of the inner surface of the boiler of about 15 lbs. By increasing the sectional area of the tube, the pressure is not increased, but only distributed over a larger surface of the vessel. A boiler, 3 feet long, 2 feet wide, and 2 feet deep, with a pipe 28 feet high proceeding from the top, will sustain a pressure of 66,816 lbs., or nearly 30 tons. A wrought-iron saddle-shaped boiler, such as that shown in Fig. 2258, is a good form. The size will of course depend on the extent of pipe to be served; but as a general rule, 1 square foot of boiler should be allowed to 50 feet of 4-inch pipe, the temperature of which is to be maintained 140° above the surrounding air. If the temperature be 120°, the same boiler surface will heat one-sixth more pipe; if 100°, one-third more. Soft or rain-water should be used in the hot water apparatus in order that no sedimentary crust may be formed.

With respect to the size of the pipes, a diameter of 4 inches is the largest that should be used, and these are well adapted for heating hot-houses and conservatories. Pipes of 2 or 3 inches may be used for warming churches, factories, and dwelling-houses. The quantity of pipe required is estimated by Mr. Hood in the following manner:—Allowing 3½ cubic feet of air for each person in the room, or hall, &c., as the quantity per minute which is to be warmed, and 1 cubic foot per minute, as the quantity cooled by each square foot of window glass; and in hot-houses, &c., allowing 1¼ cubic foot of air per minute as the quantity to be warmed for each square foot of glass; then ascertain the whole quantity of air which is to be heated, and apply the following rule:—"Multiply 125 (the excess of temperature of the pipe above that of the surrounding air) by the difference between the temperature at which the room is purposed to be kept when at its maximum, and the temperature of the external air; and divide this product by the difference between the temperature of the pipes and the proposed temperature of the room; then, the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed per minute, and this product divided by 222 (the number of cubic feet of air raised 1° per minute by one foot of 4-inch pipe), will give the number of feet in length of pipe 4-inches diameter, which will produce the desired effect." For 3-inch pipes, multiply by 1·33 the number of feet of 4-inch pipe obtained by the above rule; and for 2-inch pipe multiply this quantity by 2.

The size of the pipe selected must, of course, depend on the circumstances of the case. If the heat is to be maintained after the fire has gone out, large pipes should be used; but if the heat is not wanted after the fire is extinguished, small ones will be best. It is not desirable to make the main pipe of larger diameter than the branches, unless these extend to a considerable distance. If an 8-inch main supply 4 branches, and this main be reduced to 4 inches, the water must travel 4 times faster through the smaller pipe to perform the same amount of work and in such case the water will lose only half as much heat in passing through the small main, as it would do in ascending the larger one. Hence a small main may have advantages over a large one; for it is desirable to economise the heat, until it gets to the point from which it begins to be distributed.

It is surprising how small a force is required to generate a current in the hot-water apparatus. It is merely the difference between the temperatures of the water in the boiler, and that in the pipes; and even from this force large deductions must be made for friction. If the temperature of the water in the descending pipe be 170°, and that in a boiler 12 inches high, 178°, the difference in weight is 8·16 grains on each square inch of the section of the return pipe. In an example given by Mr. Hood, the boiler is 2 feet high; the distance from the top of the upper pipe (which proceeds in a horizontal direction from the top of the boiler) to the centre of the lower pipe, 18 inches, and the pipe 4 inches in diameter; the difference of pressure on the return pipe will be 153 grains, or about ⅓ ounce, and this will be the motive power of the apparatus, whatever length of pipe be attached to it. With a boiler containing 30 gallons of water, and 100 yards of 4-inch pipe, there will be 190 gallons, or 1,900 lbs. weight of water kept in continual motion by a force equal to only one-third of an ounce! So feeble a force is liable to be overcome, unless care be taken in the arrangement and fixing of the pipes. The pipes must be so disposed that the water in its descent be not obstructed by differences of level, or angles where air may accumulate; for, if the stream be divided by a bubble of air, the circulation is arrested. Whenever an alteration in level occurs, an air-vent must be provided.

We now proceed to notice the high-pressure apparatus which was contrived by Mr. Perkins. In its

simplest form, this apparatus consists of a continuous pipe of wrought-iron, 1 inch in external, and $\frac{1}{2}$ inch in internal diameter, filled with water, a portion of the pipe, about $\frac{1}{8}$th of the whole length, being coiled up in the furnace, and supplying the place of a boiler. The coil F C, Fig. 2259, being entirely surrounded by the fire, the water heats rapidly; and, becoming charged with minute bubbles of steam, a rapidly ascending current is formed. At the upper part of the pipe, the steam condenses into water, which unites with the column in the return pipes *c c*. The descent is rapid, in proportion to the expansion of the water in the ascending column; the rapidity of the current being in proportion to the relative specific gravity of the two columns. The expansion of the water by heat is allowed for by connecting a pipe E, $2\frac{1}{4}$ inches in diameter, with the highest point of the apparatus. The filling pipe is inserted at the lower part of the expansion pipe. In filling the apparatus, the expansion pipe is left open at top; air is expelled from the pipes by pumping water repeatedly through them; and, when the apparatus is properly filled, the filling pipe *f* and the expansion tube E are closed with screw plugs *p*. The expansion pipe is not, of course, filled with water; and, in general, from 15 to 20 per cent. of expansion space is allowed. The furnace is generally so placed as to allow the tube from the top of the coil to be carried in a direct line *a* to the

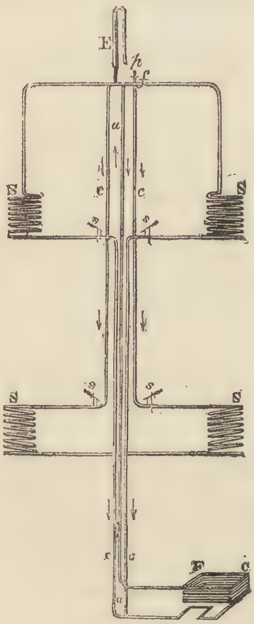


Fig. 2259.

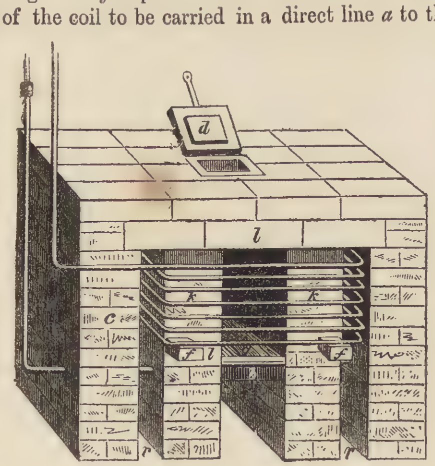


Fig. 2260.

highest point; and from this 2 or more descending columns *c c* can be formed, and be made to circulate through different parts of the building, uniting into one pipe just before entering the bottom of the coil in the furnace. The pipe is also formed into coils S S in different parts of the building, each coil being placed within a pedestal, surrounded by trellis-work; or the coil may be sunk into the floor when of stone, or placed behind a skirting, or in the fireplaces of each floor, the flues being stopped. A common form of furnace for heating the coil is shown in Fig. 2260. It varies from $3\frac{1}{2}$ to 6 feet square, according to the extent of pipe. The fire occupies a small space in the centre, raised about a foot from the ground, and the fuel is supplied through the hopper door *d*. The outer casing *c* is of common brick-work; *l l* are Welsh fire-lumps; *f f* are fire-bricks, supporting the coil *k*; *r r*, reservoirs for the dust and soot, which would otherwise clog the coil; *b*, bearing bars for the grate; *g*, the grate: the fire-door is double, and there are also doors to the ashpit and dust reservoirs. Fig. 2261 shows the descending tube entering the fire-chamber, and passing through

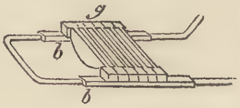


Fig. 2261.

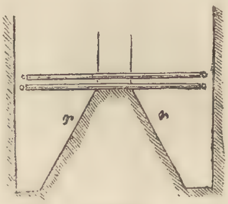


Fig. 2262.

the bearing bars *b b*, of the grate *g*. Fig. 2262 is a section of the back well or reservoir *r r*, formed so as to support the coil, and to cause the soot and dust to fall to the bottom.

In this arrangement, the ignited coal is surrounded on three sides by a thickness of 9-inch fire-brick, or Welsh lumps; the hopper door is also placed in one of these lumps; the coil is contained in a chamber round the fire-brick, $4\frac{1}{2}$ inches wide; the pipe enters this chamber, passing through the bearing bars of the grate, which tends to preserve the grate from burning; the pipe passes out from the top of the coil, at the upper part of the chamber. The smoke passes through the chamber containing the pipes, and escapes through an opening at the back. The coil is in actual contact with the fire only in front. The best fuel for this furnace is coke or anthracite. The furnace may be placed in a cellar, or be completely removed from the building. The heat of the furnace can be moderated by closing the ashpit door, and opening the furnace door, or the reservoir doors, so as to lessen the draught, and admit cold air to the coil.[1]

6. *Warming and cooking by gas.*—The general introduction of gas into private houses has led to various contrivances for warming rooms and cooking food by its means. The open fire is so much associated with the ideas of domestic comfort in this country, that attempts have been made to combine the economy and cleanli-

(1) "The high-pressure system is expounded in Mr. Richardson's "Treatise on the Warming and Ventilation of Buildings," &c., second edition, 1839. Mr. Hood's work shows the relative merits of the three methods of warming, viz. by steam, and by low and high pressure water apparatus.

ness of gas with that condition in warming apartments. Mr. Goddard, engineer of the Ipswich Gas Works, has contrived a stove in which asbestos is used for giving visibility to the fire. This stove has the further advantage of being portable; the sides fold down so as to form a box of moderate dimensions. Fig. 2263 represents it open, with the flattened coil-burner ready

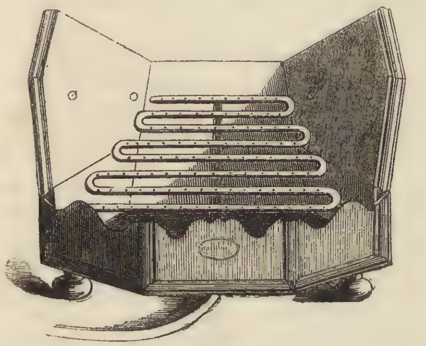


Fig. 2263.

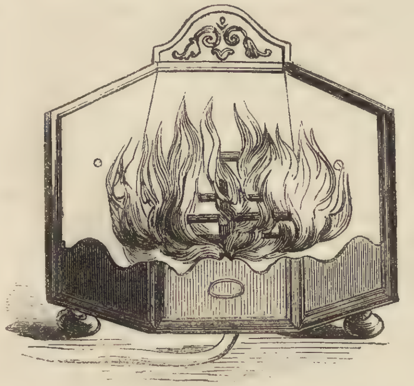


Fig. 2264.

for use. Fig. 2264 shows the stove not intended to collapse or shut up; here the effect of the burning fire is shown. The fire-chamber is coated internally with porcelain, and within this the tubular burner is set at an angle of 45°. A quantity of asbestos shavings is first spread over this burner, and the gas being turned on and ignited, the effect is something like that of a common fire. The porous nature of the asbestos admits an abundant supply of air, so that the gas is consumed without the production of smoke. A consumption of about 7 cubic feet of gas per hour, at a cost of about 4*d.* for 12 hours, is sufficient to heat a good-sized room. The asbestos, which is indestructible, costs about 2*d.*

Ward's gas stove consists of a plate of thin sheet-iron, which is fitted into an ordinary fireplace after the manner of a fire-board, about 2 inches within the projection of the mantel-piece; about 3 inches in front of the back plate, a similar plate of sheet iron is fastened by bolts; a third plate, somewhat smaller, is placed about 1 inch from the second plate and enclosed at the top, bottom, and sides, so as to form a chamber 2 or 3 feet square, and 1 inch in thickness. Towards the bottom of the last plate is cut a long aperture, closed by a sliding plate which acts as a door, for lighting the jets of gas and admitting a small quantity of air. A little below the aperture is introduced a pipe in which 3 or more gas jets are fixed, arranged so that the flames may extend laterally and not touch the iron. From the top of the enclosed chamber, a pipe 1¼ inch in diameter proceeds through the second and first plates into the chimney. The inventor states that this apparatus will raise the temperature of an ordinary-sized room 5° or 10° with a consumption of about 3 cubic feet of gas per hour, or at the cost of 2*d.* for 10 hours. The stove by its vertical position exposes a considerable surface for the absorption of heat from the gas, and for the radiation of heat, and it projects only 2 or 3 inches into the room.

Mr. Graham, of the Eagle Hotel, Glasgow, has contrived a gas cooking-stove, shown in sectional elevation Fig. 2265, and in plan Fig. 2266. The two end plates

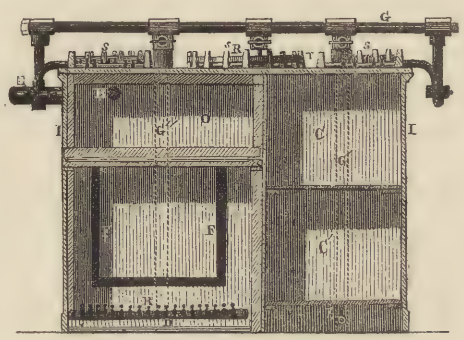


Fig. 2265. GAS COOKING-STOVE.

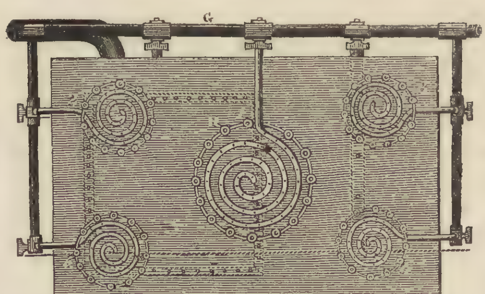


Fig. 2266. PLAN.

I I are of iron, with a back plate of the length of the range, and a top plate: the front is furnished with 3 doors. The gas is conducted from the main by a pipe G, from which 7 branches spread to corresponding burners inside and on the top of the range. The 5 branches 1, 2, 3, 4, 5 lead to 3 different sizes of burner scrolls intended for boiling or heating vessels placed on the top of the range. Each pipe passes close over the top of the range, and the terminal volute rests on the surface. It is studded throughout with small gas burners, and is surrounded by a ring of studs S S rising from the top of the range. These studs stand up somewhat higher than the burners, and are connected together by a flat metal ring R, which retains the heat from the burners and guards them from

contact with atmospheric currents. The vessel to be heated is placed on a ring of supporting studs corresponding to its size, and the gas flames thus play upon the bottom of the vessel. The internal space is divided into 2 unequal portions by a vertical plate, and the smaller space is subdivided into 3 portions by movable shelves. A branch G′ from the main gas-pipe G, is bent downwards and passes into the bottom space, terminating in a short horizontal piece carrying the burners *b*, the heat from which warms the two upper chambers C C′, in which plates are heated or food kept hot. This side is closed by a single door. The larger division has a branch G″ from the pipe G, entering near the bottom and terminating in a rectangular burner tube R, furnished with a number of burners inclined inwards. From the division-plate above, a wire frame or netting F is suspended for carrying the meat to be roasted, the gravy or dripping falling into the bottom vessel D. The upper division O is an oven heated by the same burners R. The whole of this side, appropriated to roasting or baking, is lined with fire-brick, which absorbs and then radiates the heat upon the articles which are being cooked. The bottom of the oven is also lined with fire-brick. Each burner is regulated by a stop-cock, and the apertures of the burners are very minute. The hot air and vapour escape by the waste pipe E E. This apparatus appears to be very complete, and it is stated that a dinner for 40 persons has been cooked with it at the cost of only 7*d.* for gas.

The foregoing examples will sufficiently indicate the kind of apparatus employed in warming and cooking by gas.

Section II.—On the various means proposed or adopted for the Ventilation of Buildings.

The theoretical perfection of ventilation is, to render it impossible for any portion of air to be breathed twice in the same building. In the open air, ventilation is perfect, because the breath, as it leaves the body, has always a higher temperature than the air of any habitable region of the earth. The organs of respiration are contrived with such marvellous self-adjusting skill, that while the Esquimaux, who breathes air at the temperature of zero, has to raise it 98° before it is expired from his lungs, the inhabitant of the tropics may have to raise its temperature only 3°. In England, with a mean temperature of 50°, each individual has to warm one gallon of air every minute, on an average, 48°. The whole amount of carbon consumed by the human body does not exceed 9 ounces per diem, a considerable portion of which is expended in warming the breath.

This great expenditure of heat and power is for the purpose of ventilation; for carrying away the noxious air, and bringing us a supply of fresh. "This necessary end it effects in the most perfect manner, by rendering the respired breath more bulky and specifically lighter than the surrounding fresh air; thus causing it, immediately on leaving the nostrils, to ascend, and be replaced by an ingress of fresh air, ready to be received at the next respiration. By what other means could the end be insured? Had the breath been returned from the lungs with its specific gravity unaltered, the freshness of the next supply would have depended entirely on the force with which the previous breath was expelled, the distance to which it was carried,—the respiration, at any moment, of wholesome or deadly air would have depended on mere chance,—and the stratum of air in which several persons or animals were collected, would very soon become irrespirable unless renewed by wind, which would be as likely to bring worse air as better. Still more disastrous would be the results if the respired air were denser than the fresh. Accumulating on the ground in a noxious layer, and left to spread itself upwards only by the slow process of chemical diffusion (acting under the most unfavourable circumstances), or to be stirred up in deadly whiffs by every wind, it would cover the earth with an universal malaria, and render the stratum in which animals live the most unfit portion of the atmosphere to sustain them.

"But it is another essential feature of this exquisite mechanism, that the lightness of the respired air should be only temporary. It is lighter, only because *warmer* than the pure air; and it preserves its buoyancy only as long as this warmth is not dissipated. Were it *permanently* lighter, it would accumulate in the upper regions, and descending only by chemical diffusion (acting again under the worst conditions, and, therefore, with extreme slowness), it would not be supplied to the vegetable world so quickly as it now is, and consequently could not be purified so quickly as it is vitiated by animals; so that the present equilibrium could not be maintained, but the whole atmosphere would go on progressively deteriorating, and the respirable stratum diminishing in height. But the vitiated air is, *at equal temperatures*, heavier than the fresh; for it contains the whole of its original ingredients, with the addition of a portion of carbon, which has been dissolved in it without increasing its bulk. The change which it has undergone in respiration consists in the mechanical addition of some steam, and the chemical addition of some carbon. Unless its temperature were altered, the steam would indeed augment its bulk in a slightly greater ratio than its weight, and thus render it specifically a little lighter; but this effect (varying greatly according to its original hygrometric state) would never nearly equal the contrary effect of the carbon, which adds only to its weight, and not at all to its bulk. On the whole, then, the vitiated air would sink to the ground were it not for its warmth, to which alone it owes that ascensional force which removes it out of the way of second respiration. As soon as it has cooled to the atmospheric temperature, this relation is reversed; and the impure air being now heavier than the pure, but raised above vast quantities of it, is in the best situation for the speedy action of that diffusive force by which gases permeate each other; and the difference of densities, instead of hindering, promotes this process, and brings down the carbonic acid within reach of the plants it is to nourish, but in a state so diffused and diluted as to be of

the least possible prejudice to animals. We must never overlook this twofold provision, by which the breath is, when first exhaled, lighter, but when cold, *heavier* than pure air; at first lighter, that it may not mix with it, but be kept separate and removed out of our way; but afterwards heavier, that it may not accumulate, but be mixed and diluted, and repurified as soon as possible."[1]

If the ventilation is thus perfect in the open air, it is miserably imperfect in most human habitations. Within doors, the same law is in action as without. The hot breath ascends, and would escape if proper channels were provided for its exit, and due provision were made for the entrance of fresh air below. But in our flat, ceiled rooms, where there is no escape for the heated, and consequently the lightest air of the room, it becomes cooled, and is soon the heaviest: it descends to be breathed over again, and in this condition it acts as a poison.

It is the undisputed opinion of medical men who have studied this subject, that the breathing of bad air is a more fruitful source of disease than any other. Dr. Arnott, in a letter to the *Times* newspaper of the 22d September, 1849, says:—"I assume that your readers know that fresh air for breathing is the most immediately urgent of the essentials to life, as proved by the instant death of any one totally deprived of it through drowning or strangulation; and by the slower death of men compelled to breathe over again the same small quantity of air, as when lately seventy-three passengers were suffocated in an Irish steam-boat, of which the hold was shut up for an hour by closely covered hatches; and by the still slower death, accompanied generally by some induced form of chronic disease, of persons condemned to breathe habitually impure air, like the dwellers in crowded, ill-ventilated rooms, and foul neighbourhoods; and, lastly, as proved by the fact, that pestilence or infectious diseases are engendered or propagated almost only where impurities in the air are known to abound, and particularly where the poison of the human breath and other emanations from living bodies are allowed to mingle in considerable quantity—as instanced in the gaol and ship fevers, which so lately, as in the days of the philanthropist Howard, carried off a large proportion of those who entered gaols and ships; and as instanced in that fearful disease, which, at the Black Assizes at Oxford, in July 1577, spread from the prisoners to the Court, and within two days had killed the judge, the sheriff, several justices of the peace, most of the jury, and a great mass of the audience, and which afterwards spread among the people of the town. This was a fever which did its work as quickly as the cholera does now. Assuming that these points are tolerably understood, I shall proceed to show, that from faults in the construction and management of our houses, many persons are unconsciously doing, in regard to the air they breathe, nearly as fishes would be doing in regard to the water they breathe, if, instead of the pure element of the vast rivers or boundless sea streaming past them, they shut themselves up in holes near the shores, filled with water defiled by their own bodies, and from other foul sources. And I shall have to show, that the spread of cholera in this country has been much influenced by the gross oversights referred to. All the valued reports and published opinions on cholera go far to prove, that, in this climate at least, any foreign morbific agent or influence which produces it, comes comparatively harmless to persons of vigorous health, and to those who are living in favourable circumstances; but that if it find persons with the vital powers much depressed or disturbed from any cause, and even for a short time, as happens from intemperance, from improper food or drink, from great fatigue or anxiety, but, above all, from want of fresh air, and, consequently, from breathing that which is foul, it readily overcomes them. It would seem as if the peculiar morbid agent could as little, by itself, produce the fatal disease, as one of the two elements concerned in a common gas explosion, namely, the coal gas and the atmospheric air, can alone produce the explosion. The great unanimity among writers and speakers on the subject, in regarding foul atmosphere as the chief vehicle or favourer, if not a chief efficient cause of the pestilence, is seen in the fact, of how familiar to the common ear have lately become the words and phrases, *malaria, filthy crowded dwellings, crowded neighbourhoods, close rooms, faulty sewers, drains and cesspools,* or *total want of these, effluvia of graveyards,* &c., all of which are merely so many names for foul air, and for sources from which it may arise. Singularly, however, little attention has yet been given from authority to the chief source of poisonous air, and to means of ventilation by which all kinds of foul air may certainly be removed.

"A system of draining and cleansing, water-supply and flushing, for instance, to the obtainment of which, chiefly, the Board of Health has hitherto devoted its attention, can, however good, influence only that quantity and kind of aerial impurity which arises from retained solid or liquid filth within or about a house, but it leaves absolutely untouched the other and really more important kind, which, in known quantity, is never absent where men are breathing, namely, the filth and poison of the human breath. This latter kind evidently plays the most important part in all cases of a crowd, and, therefore, such catastrophes as that of the Tooting school, with 1,100 children, of whom nearly 300 were seized with cholera, of the House of Refuge for the Destitute, and of the two great crowded lunatic asylums here, where the disease made similar havoc,—for places so public as these, and visited daily by numerous strangers, could not be allowed to remain visibly impure with solid and liquid filth, like the Rookery of St. Giles's, and other such localities. Now, good ventilation, which, although few persons comparatively are as yet aware of the fact, is easily to be had, not only entirely dissipates and renders absolutely inert the breath-poison of inmates, however numerous, and even of fever patients; but in doing this, it necessarily at the same

(1) From a paper on Ventilation, in "The Architect" for 1850.

time carries away at once all the first-named kinds of poison, arising from bad drains, or want of drains, and thus acts as a most important substitute for good draining, until there be time to plan, and safe opportunity to establish such. It is further to be noted, that it is chiefly when the poison of drains, &c., is caught and retained under cover, and is there mixed with the breath, that it becomes very active, for scavengers, nightmen, and gravediggers, who work in the open air, are not often assailed with disease: and in foul neighbourhoods, persons like butchers, who live in open shops, or policemen, who walk generally in the open streets, or in Paris, the people who manufacture a great part of the town filth into portable manure, suffer very little."

But as most persons pass a very large portion of their time within doors, and at least one-third of their existence in bed-rooms, it becomes of the utmost importance that these rooms should be tolerably healthy: and such they cannot possibly be unless provision be made for the escape of foul air, (*i.e.* air that has been breathed once, or has once served to support combustion,) and the entrance of fresh.

A large number of plans for ventilation have been proposed; but they may all be divided into two classes, *natural* and *artificial.* Natural ventilation resembles the process as it is carried on out of doors; no machinery is used to draw the foul air out, or to pump in fresh; but the heated products are conducted away by channels opening from the highest part of the room, and fresh air is admitted by openings in the lowest part. In artificial ventilation, the air is set in motion by machinery, or by the action of heat or steam artificially applied. Artificial ventilation is by some writers divided into *plenum* and *vacuum.* In plenum ventilation, pure air is forced by machinery into the building, and the vitiated air is left to escape by channels made for the purpose, or by crevices in the doors, windows, &c. In vacuum ventilation, the interior air is exhausted or drawn out of the building, the fresh air being allowed to enter by proper channels. These distinctions are not of very great importance, and we shall not be particular in observing them.

The first consideration in ventilating a building is as to the quantity of fresh air required to be introduced. Tredgold estimates that for each individual there should be provided 4 cubic feet of fresh air per minute. This supposes, not that each individual's respiration converts in one minute the oxygen of 4 cubic feet of air into carbonic acid, but that 3 cubic feet of air are contaminated in the process so as to be unfit for respiration, and that 1 cubic foot of air is rendered equally unfit by the combustion of one candle. Hence, a room containing 200 persons will require to have 800 cubic feet of air passed through it in that time, or rather more than would fill a room 9 feet square, and 9 feet high.

The form of ceiling best adapted to ventilation is the domed, coved, arched, or groined, from the most elevated point of which should proceed a tube or shaft, leading to a chimney or air-flue erected at the side of the smoke chimney, the warmth of which will increase the force of the ascending current. The amount of ventilation may be regulated by a plate *v*, Fig. 2267, balanced by a weight attached to a cord or wire *c* passing over a pulley *p*, suspended from *s*, and capable of being moved by a handle in the room. In the arrangement shown in Fig. 2267, the ventilation is supposed to be let into the wall *w w*. It is more difficult to ventilate in summer, than in winter. There should not in warm weather be a greater difference than 10° between the air inside and that out, and on this datum Tredgold gives the following rule for finding the area of the ventilating tubes:—Multiply the number of persons who are to occupy the room by 4, and divide this product by 43 times the square root of the height of the tubes in feet, and the quotient is the area of the ventilator tube in feet. The height of the tubes is estimated from the floor of the room to the place where the air escapes into the atmosphere; and where there are more tubes than one, they should all be of the same height: otherwise cold air will blow down some of them, or the effect of the shorter tubes will be less than that of the others. Several tubes from the same level may, however, open into one common shaft, and this may be furnished with a vane, to turn its aperture from the wind, or a top of thin metal painted of a dark colour may be used, as in Fig. 2268. The upper cap prevents wind from blowing down the shaft. In a steady horizontal wind the cap is not wanted, for the wind moving in the direction shown by the arrow in Fig. 2269, is deflected and rises over the opening of the shaft, drawing the air out of the flue, instead of impeding its exit. The shaft must not be too large, or a double current or eddies will be formed in it.

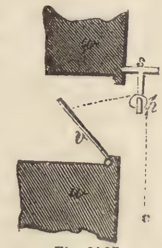


Fig. 2267.

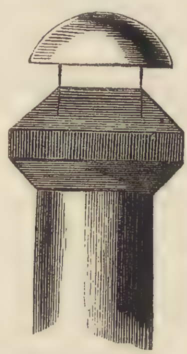


Fig. 2268.

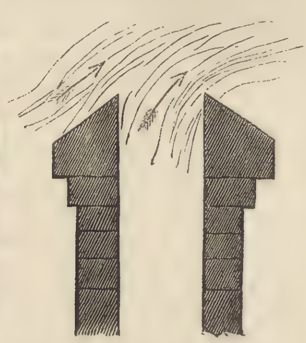


Fig. 2269.

The spaces for admitting fresh air should be near or in the floor; and these should present the same area as the exit tubes, or even larger, to prevent a rapid influx of air.

In hospitals, infirmaries, &c., Tredgold recommends an increase of ventilation, and names 6 feet per minute for each individual.

In perfect ventilation, the impure or noxious air is removed as soon as it is produced, and therefore, in any good system, the ventilating force should always be in action; and this is especially the case in places where the air is tainted by disease. The tendency of airs to mix is increased by agitation; hence the air should not be agitated, except when it is passed in large quantities through the wards for the sake of purification.

In any natural system of ventilation, where the air is left to escape by its own levity, the discharge tubes should be of uniform diameter, since any enlargement produces eddies and interrupts the discharge. Each tube should be distinct in itself, for if currents be let into it from different apertures, they cross each other and interrupt the flow.

The ventilating flue is subject to the same laws as those which regulate the chimney. [See CHIMNEY.] Air expands about $\frac{1}{480}$th of its volume for a degree of Fahrenheit from 32° to 212°. Now, if a ventilating flue 10 feet high have the air contained in it raised 20° above the temperature of the air outside, the expansion due to this increase of temperature would be $\frac{20}{480}$ths, or $\frac{1}{24}$th of its bulk. This would so far diminish the density of the heated column, that it would require $10\frac{1}{2}$ feet thereof to counterbalance a height of 10 feet of the outer air. In chimneys, the velocity of efflux is equal to that of a heavy body falling through the difference in height of the two columns, and in the present case, the difference of 5 inches is equal to 5·174 feet per second, or 310 feet per minute, and this is the velocity with which a heated column of air would pass through the ventilating tube; and if the sectional area of this be 1 foot square, then 310 cubic feet will, according to this calculation, escape per minute. A deduction from this of $\frac{1}{4}$th to $\frac{1}{3}$d must be allowed for friction due to roughness in the tube, or angles or bends in it, or to the pressure of minutely-divided carbon in the air, whereby its density is increased.[1] The number of cubic feet of air per minute discharged by a ventilating shaft is equal to 8 times the square root of the difference in height of the 2 columns of air in decimals of a foot. This number, reduced $\frac{1}{4}$th for friction, and the remainder multiplied by 60, gives the rate of efflux per minute, and the area of the tube in feet or decimals of a foot multiplied by this last number, gives the number of cubic feet of air discharged per minute.

The lower openings for the admission of fresh air must be of larger area than those for the escape of the hot air; otherwise there will be a double current established, cold air passing down one part of a ventilating shaft while hot air is ascending through the same shaft. In churches and crowded assemblies where the only means of ventilation in summer is by open windows, these double currents may be noticed, the same aperture admitting fresh and allowing foul air to escape, thus exposing persons near to dangerous draughts, and cooling the foul air, so as to prevent its escape.

In the ventilation of a church, or other public building, Tredgold advises that the spaces for the admission of cold air be abundantly large, and divided as much as possible; they should be in or near the floor, so that the air may not have to descend upon the heads of the congregation. By making the openings large, and covering them on the inside with rather close wire-work (64 apertures to the square inch), most of the current may be prevented; and it may be still further prevented by bringing tubes under the paving to admit fresh air into the central parts of the church. Of course these openings must be provided with shutters, so as to close them when desirable. Where the vent tubes can be carried up vertically from the ceiling to the top of the building, it is better to do so, because the friction of the hot ascending current is thereby diminished. If the vent be made through the ceiling of a church into the space in the roof, and from this space an air-tube be taken up within the steeple or bell-turret, an effectual ventilation may be obtained without adding outlets to the roof: or a common louvre-boarded top will answer for an outlet from the roof. All side and end windows should be kept closed; for if the apertures at the ceiling be of the proper size, and due provision be made for supplying fresh air, these open windows, as already explained, will diminish, not increase, the amount of ventilation. The reason has been already stated why ventilation is difficult to maintain in warm weather. Of course, it becomes especially so in very calm warm weather. Mr. Tredgold gives a case of this kind:—Suppose we wish to provide ventilation sufficient to prevent the internal air from being of a higher temperature than 5° above that of the external air. Now, if the external air be at 70°, we shall not be able to keep the internal temperature down to 75° with a less escape of air than $2\frac{1}{2}$ cubic feet per minute for each person; because each person will heat, at least, that quantity of air 5° in a minute, at these temperatures. When a church contains 1,000 persons, and the height from the floor to the top of the tube is 49 feet, the sum of the apertures that will allow 2,500 cubic feet of air per minute to escape, when the excess of temperature is 5°, must be equal to 12 square feet. If the height be only 36 feet, the size of the aperture must be 14 square feet nearly. When the ceiling is level, this area should be divided among five or more ventilators, disposed in different parts of the ceiling; but in a vaulted or arched roof, three are recommended to be placed in the highest part of the ceiling, as at v, in Fig. 2270. The form

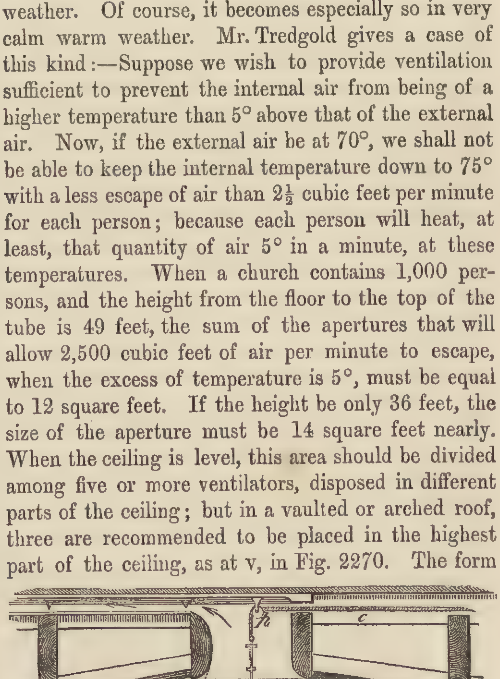


Fig. 2270.

of the mouth of the vent tube, is a circular aperture, with a balanced circular register plate, *r*, Fig. 2270, to

(1) The laws which regulate the draught of air-flues and chimneys are well discussed in Mr. Hood's work already referred to.

close it. This plate should be larger than the aperture, in order that the air may be drawn into a horizontal current, for the purpose of taking away the portion of air next the ceiling. If the tube were left without a plate, the air immediately under it would press forward up the tube, and very little of the worst air which collects at the ceiling would escape. There is, however, a defect in Tredgold's figure, since he makes the timbers dip on each side of the ventilating opening, as is indicated on one side by the dotted lines *t*, Fig. 2270. Such an arrangement as this ought always to be avoided, as it prevents the free passage of the air, and causes a stratum near the ceiling to cool before it has time to escape up the opening.

In Mr. Tomlinson's work on *Warming and Ventilation*,[1] a sectional elevation is given of a church, showing the ventilating arrangements, and it is remarked, that, "in designing and constructing a new building, flues might be made for the special purpose of supplying the interior with fresh air. Each flue might open in the cornice, pass down between the piers, and under the flooring of the church or other building, and terminate in apertures which would be covered with gratings. By disposing some of these flues on each side of the church, they would act with the wind in any direction. These exterior openings should, however, be covered with a grating, to prevent birds from building in them, and thus stopping them up."

Professor Hosking states from his own inspection, that in the churches, chapels, lecture rooms, concert rooms, &c. of the metropolis, frequently the most expensive apparatus is employed for making hot the air which is to be admitted, "but it is rare indeed to find an instance of both inlet for fresh air, whether tempered or not, and a way of escape for spent air, both in the same building; whilst the application of power either to establish and maintain the up-draught, or to force tempered air into the building, is hardly to be found at all." The same author remarks, that one essential condition to the thoroughly wholesome ventilation of a building is, that its drains be themselves efficiently ventilated. "Effectual scavengering is the first essential to wholesome ventilation." He also suggests that as most church clocks have a superabundance of power beyond their ordinary work, they would have enough to spare to work a pump or fan, for drawing off foul air.

The true principle of ventilation, as already stated, is to admit the fresh and denser air at as low a point as possible in the building which is to be ventilated, and to let out the vitiated and lighter air at the highest point of the ceiling or roof into the open air. A number of modern contrivances completely overturn this fundamental principle of sound ventilation by admitting fresh air at a point near the ceiling, or from the top window-pane furthest from the fire. Thus, a writer, who is usually sound, recommends that a space of ¼ to ½ an inch be left at the top of doors and in windows on those sides of the house which faced the points from which the mildest wind blew, and half as much space facing the north. "The advantage," he says, "of receiving fresh air at the upper part of the room is, that it comes immediately in contact with the hottest air of the room, and is thus rendered temperate before it reaches persons seated in the middle of the room or near the fireplace; whereas, when the air is admitted or drawn in by the bottom or lower parts of doors or windows, it slides along the floor towards the fireplace to supply the draught, at once cooling the feet of every one in the room, and leaving the great body of air of the apartment entirely unchanged."[2] That which the writer calls an advantage is indeed a very serious error, for by admitting the fresh air at the upper part of the room, it certainly does come in contact with the hottest air of the room, and it is precisely this hottest air which ventilation ought to get rid of, for it is charged with the fetid products of respiration and combustion; and the effect of letting in cold air upon it is to cool and condense these products, and cause them to descend to be breathed over again. This objection applies to all those arrangements of perforated zinc, glass louvres, perforated glass, &c., when they let in cool air instead of letting out the used air. And that the object is to let in cool air is evident from the statement of the inventors. Thus, in one form of ventilator, a frame of glass is hinged at the top, and moves outwards at the bottom, by the action of a quick-threaded screw, so as to form a hanging valve: an inside half-pane is arranged so as to direct the cold air *upwards*, so that it may be diffused over the room without creating any unpleasant draught. It is evident that by this arrangement the bad air, which ought to be removed, is cooled down by the entrance of fresh.

When it is stated that fresh air should be admitted at a low level in the room or building, it need not, of course, be drawn from a low level, where it is liable to contamination. It may be drawn from a considerable elevation, and still be admitted into the room at a low level. In building new houses air-ducts should be formed in the walls with the entrance just below the eaves. In old houses the air-ducts may be formed of zinc or iron pipes, or they may be wooden trunks; they should have fine wire gauze, perforated zinc, or other material stretched across them to filter the air from dust, &c. The number and position of these openings will of course depend on the amount and kind of ventilation required. Each opening may be about 6 inches in length, and 1½ inch in breadth, and at the place where it opens into the apartment the

(1) "Treatise on Warming and Ventilation, being a concise exposition of the General Principles of the Art of Warming and Ventilating Domestic and Public Buildings, Mines, Lighthouses, Ships, &c." Published (1850) in Weale's Rudimentary Series.

In the preparation of this article we have been indebted to the above work, as also to Tredgold, "Warming and Ventilation," London, 1836; Professor Hosking, "Healthy Homes," 1849; Burn, "Practical Ventilation," 1850; Bernan, "History and Art of Warming and Ventilating," &c. 1845. The "Mechanic's Magazine," and the "Civil Engineer and Practical Mechanic's Journal," contain most of the current improvements in the art.

(2) Loudon: "Cyclopædia of Cottage, Farm, and Villa Architecture."

skirting board may be perforated with small holes; or better still, the skirting board at this place may be tilted a little forward from the top, and the opening or end of the air-tube be covered with wire gauze or hair cloth, &c. This will effectually prevent cold air from streaming to the feet, and yet its entrance will be sufficiently low for the useful purposes of ventilation. The air-tube may be made to open at any other part of the room with equal facility: it may be led into the centre of the apartment, the floor being pierced for its reception, in which case the carpet will assist in diffusing it over the room. In new houses the ventilating bricks [see POTTERY AND PORCELAIN, Sec. III.] may be applied for making the air-ducts and for other ventilating openings. All these openings should, of course, be provided with flaps, so that they may be wholly or partially closed according to circumstances.

Any system of natural ventilation is liable to be modified according to the nature of the case. In Messrs. Rowan and Son's mill, at Millwater, near Belfast, the openings for the escape of foul air are furnished by the hollow iron columns which support the building. These are set as usual one above another throughout the several stories, the top of one column being connected with the bottom of the column next above it, so as to form a continuous vertical canal from the basement to the roof. Near the top of each column is an opening fitted with a trumpet mouth, into which the vitiated air passes and is carried off at the top.

Ventilation assisted by artificial heat.—In natural ventilation the products of respiration and of combustion are supposed to have sufficient ascensive force to escape of themselves through openings provided for the purpose. It may, however, happen that in the arrangements of our buildings, in the state of the wind or weather, or other causes, the shafts have not sufficient draught to discharge the foul air. In such a case, or in the first instance, to prevent the risk of failure, artificial heat may be applied to assist the draught of the foul-air flue. We have already suggested its erection next to the smoke-flue for the sake of the warmth afforded by the latter; but Dr. Arnott recommends that the smoke-flue itself be employed as the ventilating shaft. This suggestion is so valuable, and in many cases the only practicable means of drawing off foul air,—it is moreover so cheap, effective and ready in its adoption, that we are anxious to give the method all possible prominence, and we cannot do better than quote the words of the benevolent inventor. After admitting that with badly drained houses and streets, a deficient supply of water, crowded rooms, &c., ventilation cannot do more than *dilute* the aërial poisons, he says:—"Every chimney in a house is what is called a sucking or drawing air-pump, of a certain force, and can easily be rendered a valuable ventilating pump. A chimney is a pump—first, by reason of the suction or approach to a vacuum made at the open top of any tube across which the wind blows directly; and, secondly, because the flue is usually occupied, even when there is no fire, by air somewhat warmer than the external air, and has, therefore, even in a calm day, what is called a chimney draught proportioned to the difference. In England, therefore, of old, when the chimney breast was always made higher than the heads of persons sitting or sleeping in rooms, a room with an open chimney was tolerably well ventilated in the lower part, where the inmates breathed. The modern fashion, however, of very low grates and low chimney openings, has changed the case completely, for such openings can draw air only from the bottom of the rooms, where generally the coolest, the last entered, and therefore the purest air, is found; while the hotter air of the breath, of lights, of warm food, and often of subterranean drains, &c., rises and stagnates near the ceilings, and gradually corrupts there. Such heated, impure air, no more tends downwards again to escape or dive under the chimney-piece, than oil in an inverted bottle immersed in water will dive down through the water to escape by the bottle's mouth; and such a bottle or other vessel containing oil, and so placed in water with its open mouth downwards, even if left in a running stream, would retain the oil for any length of time. If, however, an opening be made into a chimney flue through the wall near the ceiling of the room, then will all the hot impure air of the room as certainly pass away by that opening, as oil from the inverted bottle would instantly all escape upwards through a small opening made near the elevated bottom of the bottle. A top window-sash, lowered a little, instead of serving, as many people believe it does, like such an opening into the chimney flue, becomes generally, in obedience to the chimney-draught, merely an inlet of cold air, which first falls as a cascade to the floor, and then glides towards the chimney, and gradually passes away by this, leaving the hotter impure air of the room nearly untouched.

"For years past, I have recommended the adoption of such ventilating chimney openings as above described, and I devised a balanced metallic valve, to prevent, during the use of fires, the escape of smoke to the room. The advantages of these openings and valves were soon so manifest, that the referees appointed under the Building Act added a clause to their bill allowing the introduction of the valves, and directing how they were to be placed, and they are now in very extensive use. A good illustration of the subject was afforded in St. James's parish, where some quarters are densely inhabited by the families of Irish labourers. These localities formerly sent an enormous number of sick to the neighbouring dispensary. Mr. Toynbee, the able medical chief of that dispensary, came to consult me respecting the ventilation of such places, and, on my recommendation, had openings made into the chimney flues of the rooms near the ceilings, by removing a single brick, and placing there a piece of wire gauze, with a light curtain flap hanging against the inside, to prevent the issue of smoke in gusty weather. The decided effect produced at once on the feelings of the inmates was so remarkable, that there was an extensive demand for the new appliance, and,

as a consequence of its adoption, Mr. Toynbee had soon to report, in evidence given before the Health of Towns Commission, and in other published documents, both an extraordinary reduction of the number of sick applying for relief, and of the severity of diseases occurring. Wide experience elsewhere has since obtained similar results. Most of the hospitals and poor-houses in the kingdom now have these chimney-valves; and most of the medical men and others who have published of late on sanitary matters, have strongly commended them. Had the present Board of Health possessed the power, and deemed the means expedient, the chimney openings might, as a prevention of cholera, almost in one day, and at the expense of about a shilling for a poor man's room, have been established over the whole kingdom."

The plan of ventilating by means of the chimney draught is by no means new. Dr. Arnott's application of it is new, and superior in simplicity to any other that we are acquainted with. The Arnott valve consists of a cast-iron box, of an oblong form, open at the two ends, and of a depth sufficient to occupy that small portion of the brickwork of the flue, which is removed for its reception. It should be placed in the flue as near the ceiling of the room as possible, and be bedded in with plaster, so that its outer edge may be flush with the wall of the room. Just within this box is placed on edge a plate of iron, sufficient to fill the opening, which plate is held in its place by means of an oblong frame, attached by thumb-screws, passing through it into the sides of the box. Projecting from the plate into the room is a short arm, the free end of which is furnished with a screw and a metal knob. By turning this knob round upon the screw, higher or lower, the specific gravity of the plate may be so nicely adjusted, that while the heated products of respiration and combustion of the room ascending to the ceiling, are sufficient to force open the valve, and escape into the chimney, any down-draught, or puff of smoke in the contrary direction, closes the valve on the other side, and prevents smoke and soot from entering the room. A spring wire is attached to the plate, and passes down to within a few inches of the mantelpiece, where it terminates in a slow threaded screw moving in a nut, fixed to the wall. On turning this screw in one direction, the valve may be permanently closed. It is of importance that the valve be nicely balanced on its edge, otherwise the down-draught of the chimney will not close it soon enough to prevent a puff of smoke into the room.

In cases where this valve does not act satisfactorily, it will generally be found that the fire of the room is not well supplied with air. Where several valves are fitted to the chimneys of the same house, it will often be found that while one acts efficiently, the others will act badly. The chimney flue in the one case will probably be found to appropriate to itself the larger share of the air of the house, leaving the other flues imperfectly supplied. These evils, together with the cutting draughts from cracks of doors and chinks of windows, scarcely admit of remedy, unless proper provision be made for supplying every fireplace with air, after some such plan as that adopted in the Polignac stove.[1]

The Arnott valve may be fitted up complete for about 10*s.* A much cheaper form has been contrived by Mr. Toynbee. It consists of a tube of iron, from 3 to 6 inches in diameter, sufficiently long for one end to remain flush with the wall of the apartment, while the other enters the chimney. The orifice of the tube in the room is covered with a sheet of perforated zinc, or of wire gauze, from the upper and back part of which hangs a flap of oiled silk, which acts as a valve, so as to allow the vitiated air to pass up the chimney, and prevent the smoke from returning into the room. Fig. 2271 shows the arrangement of this valve, *w w* represent the wall, with the iron box or tube in it, *v* the sheet of zinc or gauze, and *s* the flap of silk.

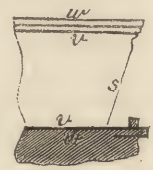


Fig. 2271.

Another modification of the Arnott valve is *Teal's Thermometric Ventilator.* This consists of a circular disk, like an ordinary damper or throttle-valve of a steam-engine, accurately balanced on a spindle carried in delicate bearings. On one side of it is an inverted syphon, with a bulb at one end, and open at the other. The lower portion of the syphon-tube contains mercury, while the bulb is filled with air. Any increase of temperature expands the air in the bulb, and drives the mercury down one leg of the syphon tube, and up the other, thus disturbing the balance of the valve, which, by its partial revolution, opens the air passage. Should the temperature of the room fall, the air in the bulb contracts, the mercury rises, and turns over the valve so as to reduce the air passage.

Many years ago Tredgold proposed to ventilate a room by means of its chimney, for which purpose he used an inverted syphon, Fig. 2272, one leg of which was to be placed in the chimney, so near to the fire as to make the air in that leg warmer than that in the other, (as at *g*, where it is supposed to be in contact with the side or back of the grate,) in which case a current would be established, the air ascending in the warm limb and passing up the chimney, while a descending current in the cooler limb would take the place of

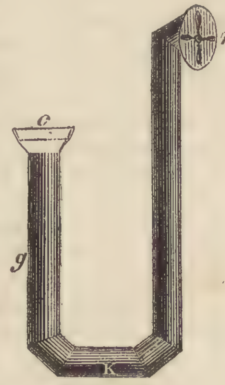


Fig. 2272.

(1) "Let it be well and clearly understood, that any success in promoting up-draught, with the effect of removing foul air from the inside of a house, will be most assuredly followed by down-draught in the chimney flues, and consequently smoky chimneys if there be fires, and soot if there be none, unless ample provision have been made for in-draught of air below, to feed any fires, and to supply the place of what the up-draught may take away."—Hosking, *Healthy Homes.*

the air in the room. The mouth of the cooler limb *n*, is to be situated close to the ceiling of the apartment, the lowest point of the curve *k* being below *g*, where heat is applied, and the aperture through which air flows into the chimney, as at *c*, should be formed so that soot may not enter it. In the figure an inverted cone is used for this purpose. The mouth of the tube should also be fitted with a register, to regulate the amount of ventilation.

The practice of ventilation by means of artificial heat is probably as old as the art of mining. The miner working in his long underground galleries is compelled to adopt some method of ventilation, in consequence of the rapid conversion of the oxygen of the air into carbonic acid, occasioned by respiration and the combustion of candles and of the gunpowder used in blasting. In the analysis of 18 samples of air from the mines of Cornwall and Devon, Mr. Henwood found the proportion of oxygen to be only 17·067 per cent., while the carbonic acid was 0·085; the nitrogen 82·848. In one instance the oxygen was 14·51, and in another the carbonic acid 0·23 per cent. These results show a diminution of oxygen from its usual per-centage of 21, and an increase of carbonic acid from 0·01, its usual per-centage, to a proportion which must be highly dangerous. The art of ventilating mines is described under COAL, but we may here mention that so long ago as the sixteenth century, Agricola, in his book *De Re Metallica*, notices the method of drawing foul air out of a mine by suspending a large fire in the middle of one of the shafts. This principle does not appear to have been adopted for ventilating crowded rooms until the year 1723, when Dr. Desaguliers was requested to endeavour to improve the mode of ventilating the House of Commons. The plan then in use had been introduced by Sir Christopher Wren, and it consisted in forming a large square hole in the ceiling at each corner of the house, and over each hole in the room above was placed a hollow truncated pyramid 6 or 8 feet high, and made so as to be closed when desired. The hot air of the house escaped by these openings, but we are not informed whether it was discharged into the open air, but only that on certain occasions the cold air above stopped the ascending currents, and sometimes poured down cold air upon the members below. The remedy contrived by Dr. Desaguliers was to construct a closet at each end of the upper room between the pyramids, and to conduct a trunk from the pyramids to certain square iron cavities which surrounded a fire-grate in each closet. When these fires were burning, air ascended from the house into the closets, then through the heated cavities, and so up the chimneys. This is a very sensible arrangement, and, we doubt not, effective. It failed, however, from a cause which we leave the author to describe in his own words:—"Mrs. Smith, the housekeeper, who had possession of the rooms over the House of Commons, not liking to be disturbed in her use of those rooms, did what she could to defeat the operation of these machines; which she at last compassed by not having the fire lighted till the House had sat some time, and was very hot; for then the air in the closets that had not been heated, went down into the House to an air rarer and less resisting, whereby the House became hotter instead of being cooled. But when the fire had been lighted before the meeting of the members, the air went up from the House into the closets and out of their chimneys, and continued to do so the whole day, keeping the House very cool."[1]

In the middle of the last century a very sensible plan was contrived by a man named Sutton, for the ventilation of ships. It was proposed to lead pipes from those parts of a ship that required ventilating to the galley fire, the draught of which would draw off the bad air. A number of experiments were tried on board a ship in the presence of some influential persons, and Mr. Watson the electrician reported thereon. He describes the copper used for boiling the ship's provisions, and the method of fixing it, with two openings below, divided by an iron grate. The first opening, having an iron door, is for the fire, the other for the ashes. In ordinary cases, the combustion of the fire is supported by air drawn through the ash-pit; but, on board ship, as both the fire hole and the ash-pit hole are furnished with doors to prevent the escape of fire, the air must be supplied by some other means. Accordingly, in Sutton's plan of ventilation one or more holes are made through the brick-work in the side of the ash-pit, and tubes of lead or copper are fitted closely therein, and conducted from thence into the well, and other parts of the ship; thus drawing off therefrom the foul air, and sending it through the fire, it escapes up the chimney. At the same time, a supply of fresh air rushes in at openings about the ship, to occupy the place of the bad air. This circulation of air not only goes on while the fire is burning, but so long as the fire-place, copper, or brick-work remains warm, as was observed on board the hulk at Deptford, when the draught of air through the tube lasted above twelve hours after the fire was taken away. "This being considered, as the dressing the provisions for a number of people will take up some hours every day, the warmth of the brick-work and flues will continue a draught of air from one day to the next. Mr. Sutton proposes thus to circulate the air by the same and no greater expense of fire, than is customarily used for the necessities of the ship." The larger the ship, the greater the number of men on board, and the larger the quantity of provisions, so that more time and fuel will be required in preparing them, the more perfect will be the ventilation. The size and number of the tubes is of little consequence, for the larger the tubes, and the greater their number, the less the velocity of the air, and *vice versâ*. Mr. Watson notices, as an essential condition of the perfect action of the tubes, that both the fire door and the ash-pit door be kept closed. In large ships there is not only a copper, but also a fire-grate like that used in kitchens. Behind this grate, copper tubes were also fixed and carried through the brick-work, one extremity projecting about a foot

(1) Course of Experimental Philosophy, vol. ii. 4to. 1744.

into the chimney, and the other end opening into the hold, or other part of the ship; so that the air rushed along this tube into the draught of hot air in the chimney. To obviate the objection to the space occupied by these tubes on board ship, it was advised that only one tube, of convenient size, be attached to the side of the ash-pit, and, passing through the main-deck, branches might ramify to different parts of the ship, these branches being carried between the beams which support the deck, until they meet the sides of the ship, where they could be conducted also between the beams into the places intended.

Such a plan as this is well adapted to the ventilation of steamers. A large central trunk might be made to feed the furnace, and into this trunk smaller branches from every cabin and sleeping birth might discharge their foul air, and thus maintain every part of the vessel in a state of perfect salubrity. Although Sutton's plan is forgotten (indeed, it can never be said to have been in use) on board ship, it has been applied for getting rid of the offensive effluvia from the coppers of soap-boilers, tallow-melters, and similar occupations, which often become a nuisance to a whole neighbourhood. The copper is set in the usual manner, and the furnace and ash-pit furnished with doors, tightly fitting; the lid of the boiler is also made to fit very tight, and a pipe rising from it is carried into a channel which opens into the ash-pit; the fœtid matters rising from the boiler are in this way made to pass through the fire into the smoke-flue. This plan is said to have answered so well that a factory which was formerly most offensive, became entirely free from bad odours.

It does not say much for the science or for the common sense of the age, that the plan of Dr. Desaguliers for ventilating a large public room, and Sutton's plan for ventilating ships, so correct as they were both in theory and practice, should have failed. When Sir Humphry Davy in 1810 was requested by the Government to propose a plan for the ventilation of the House of Lords, he sent in one which was identical in principle with that by which Desaguliers ventilated the House of Commons; Davy's plan, however, included warming as well as ventilating, and is thus stated by himself:—"To convey fresh air into the House, I propose flues of single brick connected with the flues for sending hot air through the vaults under the floor, and I propose that this fresh air should be admitted by numerous apertures in the floor of the House, and supplied to the flues by pipes of copper or plate iron from the free atmosphere. The air in this case will be always fresh, and, by regulating the fire, may be more or less heated, according as the temperature of the room is low or high.

"To carry off the foul air, I propose two chimneys, or tubes made of copper, placed above the ventilators, and connected with wrought-iron tubes, which can be heated by a small fire, if a great draught is necessary, as in cases when the House is full.

"Should this plan be adopted, there would be no necessity for opening windows; the foul air would be carried off from above; warm air or cold air, whichever is necessary, may be supplied from below, and there would not be, as now, any stagnation of air."

This plan was accompanied by a sketch, of which Fig. 2273 is a copy, in which V is one of the ventilating apertures in the ceiling of the House, covered with a chimney of copper, C; this is continued by an iron tube, I, which passes through a small furnace, F. C′ is another copper tube connected with the iron one. The upper end of this tube was only one foot in diameter; it opened into a cowl on the roof. The furnace, F, was contained in a fire-proof house erected for the purpose on the roof.

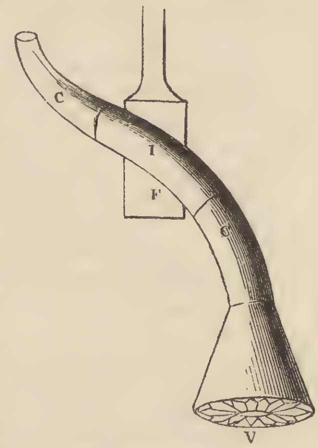


Fig. 2273.

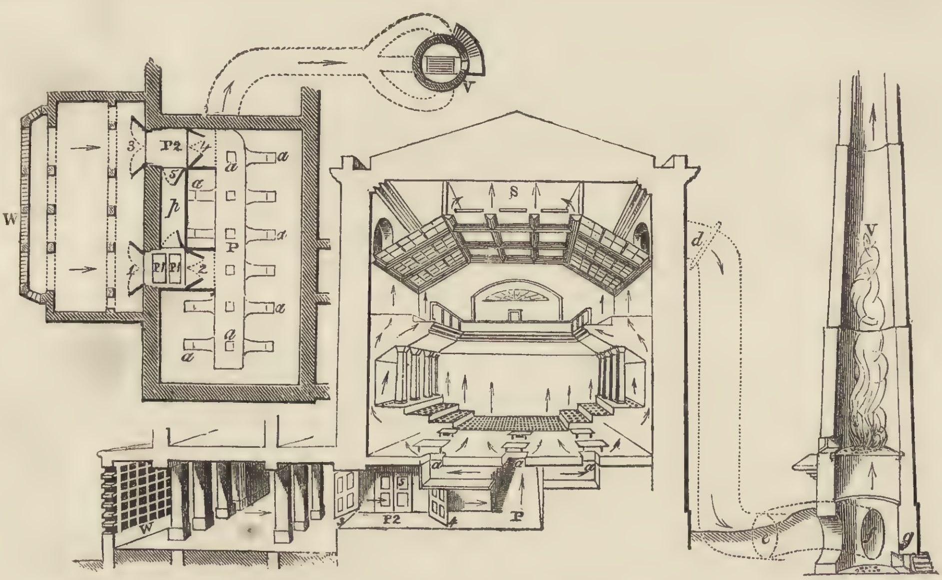
This apparatus appears to have been generally only moderately successful, and in a full House it proved to be quite inadequate to the purposes intended. Mr. James Wyatt afterwards made some alterations and additions, but the whole was destroyed in the fire of 1834.

Deficient ventilating power, the fault of the above plan, cannot certainly be charged against the method adopted by Dr. Reid for ventilating the temporary House of Commons erected after the fire. Dr. Reid's arrangements will be understood by referring to Figs. 2274, 2275, which represent a sectional elevation and ground plan of the buildings, and apparatus employed. Two or three feet beneath the floor of the House, a second floor was formed, containing about 20 apertures, each about 18 inches square. Beneath the second floor was a long passage P; opening into this, were 2 others of an equal width, P^1 and P^2; in the passage P^1 was placed the warm water pedestal. Large folding-doors were placed before the entrances, and within these passages; the temperature of the house above depended on the relative adjustment with each other of these folding-doors. Fresh air, either warm or cold, according to the season, could be produced, and changed from warm to cold, or the contrary, as the variable external temperature of the day or hour required. The fresh air entered from Old Palace-yard, through the perforated wall, W. If the folding-doors Nos. 1 and 2 were opened, and all the rest closed, the air entered the passage P, passing through the pedestals placed in P^1, and warm air only would be supplied to the House above. If air moderately warmed were required, the doors Nos. 3 and 4 were opened in addition to Nos. 1 and 2, and two currents, one cold and the other warm, were then produced, which met and blended together in the passage P, and then ascended. If air of the external temperature

only were required, the doors Nos. 3 and 4 were alone opened. If required to be only moderately warmed, Nos. 3 and 4 were opened, No. 1 half opened, No. 2 closed; the small folding-doors, Nos. 5 and 6, were then opened, and a slight current of warm air passed through the small passage *p*, and mixed with the cold current entering at P2. The folding-doors in this passage could likewise be opened when Nos. 3 and 4 were closed, and a current of warm air was then conveyed to one end of the passage P. The air, whether warm or cool, ascended through the apertures *a a a*, into the space beneath the floor of the house. Immediately over these openings were large platforms, supported by short feet, the effect of which was to disperse the great body of air admitted. The air then entered through small openings made in the actual floor of the House, about 300,000 in number, each being about $\frac{1}{8}$th of an inch in diameter on the surface of the floor, but expanding downwards, to prevent their being stopped with dirt or dust. The sides of the House under the galleries were battened or brought forward five or six inches, and in the space thus formed between the framing and the wall, the air ascended and passed out through the floors of the members' galleries, perforated for the purpose in the same manner. The floor of the House and galleries was covered with a thick horse-hair matting with large meshes, to allow the air to ascend through them.

The force which set this great body of air in motion was a ventilating shaft V, 12 feet in diameter at the base, 8 feet at the summit, and rising 110 feet above the ground, in which a powerful upward current was generated by means of a large fire.

In summer, when the air transmitted into the House was required to be cool, various contrivances were



Figs. 2274, 2275. SECTIONAL ELEVATION AND PLAN OF THE TEMPORARY HOUSE OF COMMONS, WITH DR. REID'S ARRANGEMENTS FOR VENTILATION.

proposed to be carried on in the chamber immediately behind the perforated wall W. The air was to be made to pass into the chamber P, over wet surfaces, so as to be cooled by evaporation, or ice might be suspended in netting between the piers in the chamber.

A new ceiling was also constructed a few feet below the former one, for the purpose of favouring the transmission of sound. This ceiling was divided into 3 portions, the central portion being horizontal from one end to the other; the other 2 compartments inclined so as to make an angle of 30° with the floor of the house. These 2 inclined portions were glazed, but the centre was panelled, so as to assist in the ventilation of the House. An inclination was given to the ceiling beneath the members' galleries, corresponding exactly with that of the lateral compartments in the newly constructed ceiling above.

The ventilation of the House was accomplished in the following manner:—Each panel of the centre compartment of the ceiling was raised by blocks several inches above their styles, thus admitting the air of the House into the space S, between the two ceilings. The rapid removal of this vitiated air, and the consequent rushing in of fresh air from below, was effected by the large shaft V, erected at a distance of about 20 feet from the eastern wall of the building. In this shaft about 10 feet from the surface of the ground was a very large coke or coal fire, which produced a powerful current up the shaft. The space S, between the two ceilings of the House, opened at the north end into a large square shaft, which was continued downwards, and opened underground into the circular shaft V. When therefore the current of hot ascending air was produced in the circular shaft, there was a downward draught through the square shaft, thereby rapidly withdrawing the air from within the House, and causing the fresh air to rush into it from openings

in the wall w. A damper at *d*, in the square shaft, regulated the draught in the shaft v, and consequently, as it was more or less opened, the supply of air to the House could be regulated according to the number of members present.

These extensive and powerful arrangements certainly had the effect of rapidly changing the air of the house, and furnished the means of regulating the amount of ventilation. One objection to them was the large quantity of space required for the apparatus, &c. Another objection was, that the fresh air drawn up through the hair-cloth carpet which covered the perforated floor was charged with particles of ground dust or mud from the members' feet, and this being carried up entered their eyes, nostrils and mouths, and even found its way into their lungs.

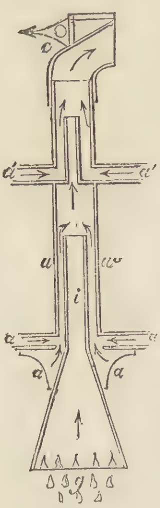


Fig. 2276.

Many years ago a clever plan was contrived by the Marquis of Chabannes for ventilating Covent Garden Theatre. In this case the large central chandelier *g*, Fig. 2276, was used as the ventilating force. Over this was placed a funnel of wrought-iron *i*, for carrying the foul air into a wooden shaft *w w*, which ascended from the ceiling to the roof, and was surmounted by a cowl *c*. The hot air at the level of the ceiling found its way into this shaft, and into it also were conducted pipes *a a* from different parts of the house for carrying off the foul air. A furnace was placed in one of the galleries, and it was fed by the vitiated air from several tiers of boxes. A similar furnace was placed over the stage, and the gas chandelier ventilated the centre.

Mr. R. Brown of Manchester has proposed to ventilate the rooms of an ordinary dwelling-house in which gas is used for illuminating, by means of the heat thereof. Through an opening in the ceiling is passed a wide tube, one end of which conveys the foul air to the outside of the house, and the other projects a little below the level of the ceiling. The gas-pipe enters on one side, and is bent so as to hang perpendicularly in the centre of the tube, and carries an annular burner at the lower extremity. The burner is surrounded by a glass chimney, which is supported at its top on a metal cone-piece, and secured to the lower extremity of the tube by screws. The whole of this arrangement is surrounded by a hemispherical glass shade, the mouth of which is uppermost, and its upper edge is a few inches below the level of the ceiling. The shade is attached at its upper edge by screws to a metal ring, and is hinged to a second ring fixed to the ventilating tube by radial arms. This outer shade can be lowered by means of a cord, for the purpose of lighting or cleaning. A highly polished metal reflector is also added to increase the effect of the light. The air of the apartment passes off in the strong draught occasioned by the burner, and a fresh supply of air is admitted at the lower part of the room.

Dr. Faraday's method of ventilating gas-burners, that is, of carrying off the products of combustion without allowing them to contaminate the air of the room, is noticed under GAS. His method of ventilating lighthouses requires a brief notice in this place.

In an ordinary lighthouse fitted up under the dioptric system [see LIGHTHOUSE], from 12 to 14 pints of oil are consumed per hour, and under the catoptric system, from 15 to 20 pints within the same period. Oil contains 78 per cent. of carbon, 11·5 of hydrogen, and 10·5 of oxygen; hence the products of combustion consist chiefly of water and carbonic acid. The hydrogen contained in 1 lb. of oil is sufficient in combination with the oxygen of the air to produce rather more than 1 lb. of water; in like manner, the carbon in 1 lb. of oil will by its combustion produce 2$\frac{86}{100}$ths lbs. of carbonic acid, to form which not less than 13$\frac{1}{4}$ lbs. or 172$\frac{1}{2}$ cubic feet of air are spoiled by being entirely deprived of oxygen. In the Tynemouth lighthouse, 19$\frac{6}{10}$ths pints of oil were consumed per hour, producing a quantity of vapour of water equal to 20 fluid pints, which vapour is condensed by the glass of the lighthouse lantern, which is kept constantly cool by exposure to the weather, and in very cold weather the water thus condensed is frozen into a crust of ice varying from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in thickness in one night. If this ice were quite transparent it would distort the light and render it dim, but the vapour which produces it is charged with minute particles of soot, which become entangled with the ice, and produce further opacity. The clearing away of this ice every morning was a work of great labour to the men, and of danger to the glass; while the large quantity of carbonic acid generated rendered the lighthouse unhealthy, if not positively dangerous to the occupants.

Under the dioptric system, the remedy was easy. All that was necessary, was to lengthen the chimney of the single central lamp, or rather to place over the glass chimney a tube of sheet-iron, carrying it through the roof of the lantern into the open air, the upper extremity of the tube being furnished with some kind of cowl or louvre. Under the catoptric system, where there are a number of lamps with reflectors, a central ventilating shaft was also formed, and over the glass chimney of each lamp was placed one extremity of a small tube, this tube being curved so that the other extremity opened into the central shaft. The tubes were supported by the frame which carried the lamps and reflectors, and as the frame revolved, the upper ends of the tubes described each a small circle within the central chimney, but without touching it. In this way the small tubes carried off the products of combustion without interfering with the reflectors. This method of ventilating succeeded under both systems of lighting, as was proved by the interior of the lantern remaining dry and healthy, and the windows bright. The plan is described by Dr. Faraday as an

adaptation of *sewerage* to the atmosphere, aërial sewers being employed to carry off the refuse of the spoiled air, instead of allowing it to accumulate in the house or apartment.

For the ventilation of collieries and mines, see COAL—MINE, MINING.

Ventilation by Mechanical Contrivances.—In the course of the last century, two men who have rendered good service to science attracted considerable attention to their inventions for the purpose of ventilating ships. These inventions were *Hales's Ventilator* and *Desaguliers' Fan.* The former consisted of 2 outer cases, each 10 feet long, 4¼ feet wide, and 13 inches deep inside, with a wooden midrif or valve fixed at one end to each case by iron hinges, and moving up and down by means of a lever 12 feet long. A number of valves fixed in the outer case, and hinged so as to open inwards, admitted the air to the interior, which air was again expelled at each rise and fall of the midrif through another set of valves, which were hung so as to open outwards. The emission valves were covered by a box with a large aperture, from which the air was conveyed by a pipe into any part of the ship that was to be ventilated. Thus this machine, in its construction and action, resembled a pair of bellows of a clumsy kind. Two men were required to work each lever, and thus to put in action an apparatus which was termed by the inventor the "Ship's Lungs." In working this ventilator, the labour was obvious, but the benefit conferred was not so apparent; for it is difficult to persuade men that respired air can be foul, when the impurities are not visible to the eye.

Although Dr. Desaguliers' fan shared no better fate on board ship than Dr. Hales's ventilators, it was nevertheless an invention of great practical value, and has continued in use up to the present time. When placed within a ventilating shaft, and made to rotate by the descent of a weight or other mechanical means, it becomes a ventilator of considerable efficacy. The fan, as originally invented in 1734, was worked by hand. It consisted of a wheel, which was 7 feet in diameter, and 1 foot wide, and had 12 radii or partitions, approaching within 9 inches of the axis, leaving a circular opening 18 inches in diameter. This wheel was enclosed in a concentric case, furnished with a blowing-pipe on the upper part, and a suction-pipe communicating with the central opening in the wheel, which was turned by a handle attached to the axis, which passed through the case, and rested on a standard. The fanner was made so as to revolve easily, but as closely to the concentric casing as possible, without any communication with the air, except through the suction and blowing pipes. To ensure this, rings of blanketing were fixed within the case, so that the edges of the vanes might be in contact therewith, and the air have no other escape than by the blowing-pipe. By the revolution of the wheel, the air within the case was rapidly impelled by centrifugal force to the circumference, where it was condensed, whirled round, and forced out, in a powerful current, through the opening of the blowing-pipe, while the partial vacuum thus formed set a current of air in motion towards the centre, which current entering thereat, and passing upwards, was distributed between the vanes, and, being driven to the circumference, passed out in a powerful continuous blast. The suction-pipe could be made to communicate with the external air by means of a pipe, or with a space containing heated air; and the blowing-pipe could be connected with a room, which could thus be filled with cool fresh air, or with warmed air, the quantity being regulated by the speed of the wheel. If foul air had to be drawn out, the suction-pipe was connected with the space containing it, and the blowing-pipe with the external air.

In the year 1736, a wheel of this description was erected over the ceiling of the House of Commons, for the purpose of drawing out the vitiated air, in the manner just described, a man being kept constantly at work, during the sitting of the House, to turn the wheel. It was stated, that this wheel was "able to suck out the foul air, or throw in fresh, or do both at once, according as the Speaker is pleased to command it, whose order the ventilator waits to receive every day of the session." This apparatus continued to be used for ventilating the House until the year 1791, when the chief clerk of the House, Mr. Holland, proposed its removal from the room over his own private apartments, to the centre of the roof immediately over the House, as being a more advantageous position. This was accordingly done, and continued in operation until 1817, when a similar contrivance was recommended for the ventilation of the House of Lords. It was not, however, erected; for, in 1820, the whole business of warming and ventilating both Houses was entrusted to the Marquis of Chabannes, whose plan has already been noticed.

In some of the large factories in Manchester and elsewhere, the fan is employed for extracting the foul air in measurable quantities. It is made to revolve at the rate of 100 feet per second. One of Messrs. Fairbairn and Lillie's excentric fans, placed at one end of an apartment about 200 feet long, when in full action throws the air so powerfully out of it, as to create a draught at the other end of the room capable of keeping a weighted door 6 inches ajar. When connected in the attics with a horizontal pipe, into which vertical tunnels from each room are inserted, it draws out the air so rapidly from them as to cause a breeze from every part of the adjoining floors, thus producing an excess of ventilation in the apartments. The simple and cheap contrivance of cast-iron boxes, placed on every story in communication with the fan, is the method adopted. A side and a front view of the fan are given in Figs. 2277, 2278, such as has been used of late years for ventilating factories, for removing through tunnels the dust disengaged in cleaning fibrous materials, such as cotton, hemp, &c., for blowing air into forge fires, and many other similar purposes. It consists of two cast-iron end plates, I I, with a central opening, *o o*, from the circumference of which the outline of each plate enlarges spirally, the

point nearest the centre being near *x*, and that furthest off being under the lower vane, *v*. This pair of parallel plates is connected by bolts, *b b*, a mantle of sheet-iron being previously inserted into grooves cast in the edges of the end plates, so as to enclose a cavity with an elongated outlet at A, to which a pipe is attached for carrying off the air in any direction. Within this

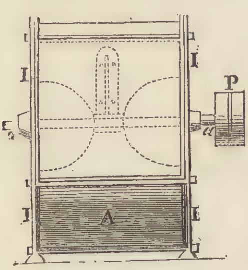


Fig. 2277.

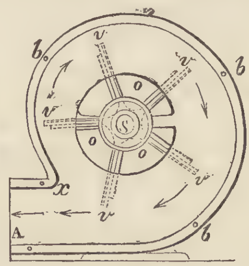


Fig. 2278.

cavity a shaft, S, revolves in bearings, *a a*, placed centrally in the frame-plates, I I. On this shaft, a boss is wedged fast, bearing 5 flat arms, *v v*, to which are riveted 5 flat plates, or wires of the shapes shown between I and I in Fig. 2277, having a semicircular piece cut out of them on each side, about the size of the end opening. On one side of the shaft, S, beyond the box-bearing, the fast and loose pulleys, P, are fitted for receiving the driving band, and for turning the wings in the direction shown by the arrow. Thus the air is driven before them out of the end orifice, A, while it enters by the side openings at *o o*. By the centrifugal force of the revolving wings, the air is condensed towards their extremities, and makes its escape from the pressure through the orifice, A, while it is continually drawn in at the sides by its tendency to restore the equilibrium. The fans are sometimes constructed so as to have their mantles concentric with their central shafts, as in Dr. Desaguliers' fan. The improved fan (Fig. 2278) is called the excentric; the air which escapes through the outlet, A, has undergone compression during its whole progress through the spiral space with the revolving wings, and is equal in density to that compressed at their extremities by the centrifugal force. The fan, therefore, discharges considerably more air than that with a chamber concentric with its wings, because, in the concentric fan, there is considerable loss of power, on account of a large quantity of air being carried round by the leaves of the fan, instead of passing out through the discharge-pipe at the circumference; but in the excentric fan, each wing or leaf, in passing the point *x*, acts as a valve to cut off the entrance of the uncondensed air, which would cause an eddy, and retard the proper current by the inertia of its particles. When the fan is required to draw air out of a series of independent rooms, it has its circular side openings, *o o*, enclosed within caps, which are connected with pipes communicating with such rooms. Slide or throstle valves may be placed in the exhausting, as well as the condensing pipes, for regulating the distribution of the rarefying or blowing power.[1]

(1) "Philosophy of Manufactures." London, 1835.

The fan produces its greatest effect when the extreme points of its leaves move through about 80 feet per second. The mean velocity of that portion of the vanes by which the air is discharged, is about 7-8ths of the velocity of the extremities; but, owing to the inertia of the air, there will be a loss in the velocity of the issuing current, which will increase with the increased speed of the vanes; so that, in general, the current will be discharged with a velocity equal to about 3-4ths of the velocity of the extremities. This velocity, measured in feet per second, multiplied by the area of the discharge-pipe in square feet, will give the number of cubic feet of air discharged per second. If the effective velocity of the vanes be 70 feet per second, and the sectional area of the discharge-tube be 3 square feet, then $70\times3=210$ cubic feet of air discharged per second, or 12,600 cubic feet per minute. As a cubic foot of air weighs 527 grains, there will be about 13 cubic feet of air to a pound; therefore $\frac{210\times60}{13}=969$ lbs. weight of air set in motion per minute, with a velocity of 70 feet per second. The height from which a heavy body must fall in order to acquire a velocity of 70 feet per second is 76·5 feet, which, multiplied by the number of pounds weight moved per minute, will give the power necessary to discharge this quantity of air at the stated velocity; and this product divided by 33,000 (the number of pounds weight that one horse will raise one foot high per minute) will give the amount of steam-power required. Therefore $\frac{76\cdot5\times969}{33,000}=2\cdot24$, or nearly $2\frac{1}{4}$ horses' power, will be required to discharge the given quantity of air at the velocity stated.[2]

A more powerful fan than the above has lately been introduced, under the name of *Chaplin's Duplex Pressure Fan*. It consists of 2 fans combined in 1, (Fig. 2279,) with a single spindle driven by a central band-pulley. The air is taken in by one case, in the direction of the arrow, and conveyed in its compressed state into the second, whence it is discharged at a much higher pressure than can be produced by a single fan. The case in which the air is first received is the larger of the two; and the second case, which contains a smaller fan than the first, subjects the air to a second compression.

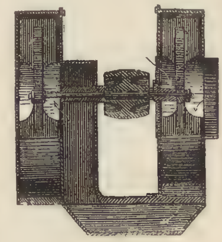


Fig. 2279.

In some contrivances, the spokes or vanes are arranged in the form of a *screw*, in which case, an ascending current of vitiated air will impart motion to it by acting on its spirals. This machine is very inferior to the fan in ventilating effect, for as soon as the condensation of the air between the spirals becomes equal to the friction between the air and the surface of the spirals, no further increase in the amount

(2) Ure, "Philosophical Transactions."

of discharge takes place. The screw will only discharge small quantities of air at a moderate velocity, so that it is not adapted to an extensive scheme of ventilation.

The *punkah*, so valuable in warm climates, is a machine which acts somewhat like a lady's fan, keeping the air of the apartment in motion, but not contributing in any way to bring in a fresh supply, or to discharge that which is vitiated. The punkah is a large broad surface of almost any material, suspended in the centre of the apartment, above a bed or table, with a line attached to one side, and passing out of the apartment through the wall to an attendant on the outside, who gives motion to the extended surface. Some years ago, a small steam-engine was procured from England by the Nabob of Oude, to work the punkahs of his palace.

Among the ancient Egyptians, there was a mode of spontaneous ventilation called the *mulguf*, or wind-conductor. This is still in use in modern Egypt, and consists of a frame erected at the top of the house, and covered in on all sides, except in the direction of the prevailing winds. The top or roof of this machine slopes inwards from the open ends to the centre, where a partition deflects the wind downwards to the apartments. The modern revolving cowl is sometimes made to act in a similar manner.

Section III.—On the Warming and Ventilation of Buildings.

In an enclosed space, or collection of enclosed spaces, such as a dwelling-house, causes are always in operation which tend to rarefy the internal air, and to set in motion currents from the outside to the inside. The presence of a human being in a room is in itself sufficient for this purpose; but it is powerfully increased by the combustion of lamps, candles, and fuel. If proper ventilating openings be made at the highest point in each room, an upward current will in most cases be established, or such a current may be determined by the introduction of a gas-flame, or of a small coil of pipe, where the building is warmed by hot water, or of a fan set in motion therein by means of a descending weight, which requires to be wound up only once in about 24 hours.

The arrangements in Sir John Robinson's house at Edinburgh are often referred to as a model for the application of sanitary arrangements; the system of ventilation is said to be so perfect, that "while the mass of air in the rooms and passages is constantly undergoing renewal by the escape of the vitiated air above and the admission of large supplies of fresh air from below, no currents are perceived in the apartments, which even when crowded with company and amply lighted preserve a remarkable freshness of atmosphere." The sectional area of the cold air passages is about 14 square feet, and they are left open in the coldest weather, provided there is not much wind. The air passages are formed of cylindrical flues of earthenware, 9 inches in diameter, built into the gables, close to the smoke-flues. The lower ends of the ventilating flues open into spaces between the ceilings of the respective rooms and the floors above; and one or more exit air-flues is provided for each room. The hot, vitiated air passes up through the ceilings by a continuous opening of about $1\frac{1}{2}$ inch in width, behind one of the fillets of the cornice, all round the rooms, and, having passed into the space between the ceiling and the floor above, it ascends by the flues in the wall, and is discharged into the vacant space between the attic ceilings and the roof, and thence through the slates to the open air. This last part seems to be a defect in an otherwise ex-

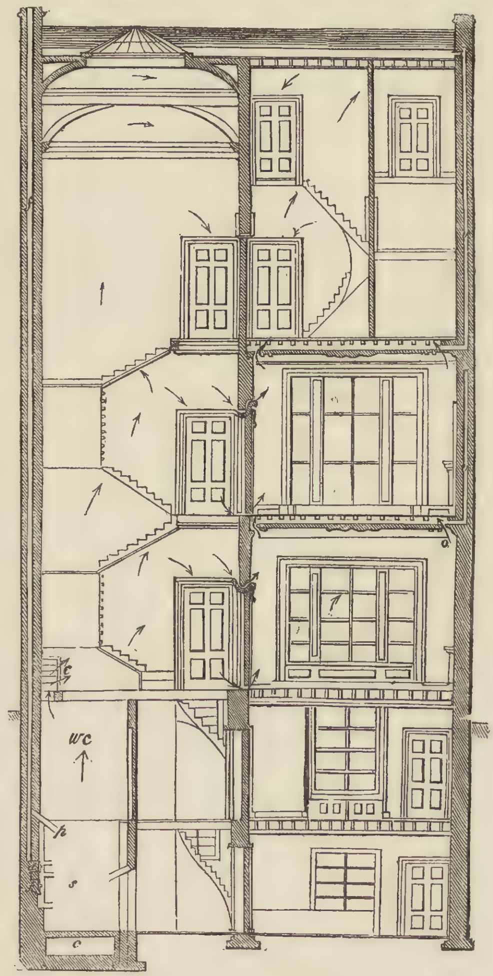


Fig. 2280. WARMING AND VENTILATING ARRANGEMENTS IN SIR JOHN ROBINSON'S HOUSE.

cellent arrangement; if the joints of the slated roof do not afford a sufficient exit for the hot, vitiated air, there will be a resistance, and consequent cooling or condensation by the cold surfaces of the slates, exposed as they are to the direct action of the outer air. A turret or louvre seems to be wanting on the roof. The passage for the hot air through the cornice is not visible from the floor of any of the rooms. The air-flues terminate above the ceilings of the attics, and *below* the roof, to prevent smoke being carried down them by reverse currents. The supply of fresh

air to the house is from a garden behind; it is conveyed by a passage *c*, Fig. 2280, which has a sectional area of 8 square feet. There is also a similar passage in front of the house. The air thus admitted is warmed by a cockle to from 64° to 70°. In very cold weather, 70° is preferred, to allow for the cooling effect of the walls and windows, and thus to maintain a constant temperature of 60° throughout the house. The air thus warmed is discharged into the well *w c* of the staircase, from which the rooms draw the supply required for maintaining the upward currents in the chimneys, and in the ventilating flues. The air from the well gets into the apartments by means of masked passages, 4 or 5 inches wide, and 4 feet long, over the doors, and by openings about 1 inch in width under each door. The sectional areas of these passages are more than equal to the areas of the chimney and ventilating flues, so that as the air within is not much rarefied, there is but little tendency in the outer air to enter at window chinks, and other apertures. The course of the air from the large aperture *c* over the stove, through the staircase, over and under the doors, into the rooms, and thence through the ceilings, and upwards by the escape-flues, is shown by the direction of the arrows: the quantity of escape is regulated by means of throttle-valves at the mouth of each escape-flue, by which the rate of the ventilating current can be increased or diminished. The kitchen is ventilated in a similar manner. One flue proceeds from the ceiling over the fireplace, and another from over the gas cooking-stoves. The first flue is built in the gable close to the smoke flue, and the second passes upwards by the back of the cistern and pipes of a watercloset, thus protecting them from the action of frost. *p* is the pipe conveying the smoke from the fire which heats the cockle into the smoke flue *f f*. At *d* is a damper for regulating the draught of this fire.

In the above arrangement, the cockle-stove was used as the source of heat. There are many cases in which the Arnott stove may be used as a means of warming and ventilating, when placed in one of the lowest rooms of the house, and used as a source of heat to the air supplied to the house from without, as in the following ingenious application of it by Mr. Charles Cowper. In a letter to the editor he says:—

"I tried an experiment this winter, and derived considerable advantage from it, for the water in the jugs in the top rooms of my house did not once freeze, notwithstanding the intense cold. My house consists

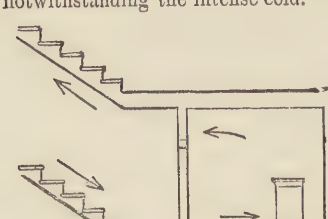


Fig. 2281.

of four floors of two rooms each, with a wash-house outside at the back. The back kitchen is but little used, so I put one of the smallest Arnott stoves, 14 inches square, in it; applying a sheet-iron plate to close up the chimney of the kitchen range. This heated the staircase a little way, but the heat could only get up by means of an upward current under the flight of stairs, and a downward current on the stairs, as shown in Fig. 2281. I found that in all states of the wind, there was a strong inward current of air at a door opening into the outer air from the back kitchen. There were also inward currents of air even at the top windows of the house. I believe this is the case in nine houses out of ten, although the house being warmer than the outside, the air ought to enter at bottom, and escape at top. This shows that there is no proper entrance provided for the air, and consequently it is no wonder that we have smoky chimneys. I therefore had a zinc pipe, 5 inches diameter, A, Fig.

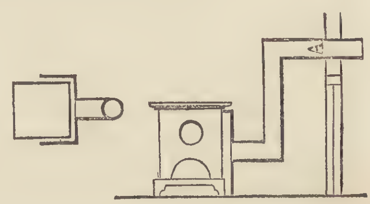


Fig. 2282.

2282, brought through the wall, and directed against the side of the stove, to which I fitted a piece of sheet-iron, so that all the air entering at the pipe might be forced to spread itself over the exterior of the stove. I have a damper in the pipe, but it is left full open when the stove is in use. I have thus a 5-inch column of air always pouring into the house, and heated to a comfortable temperature by the stove. This has much diminished the tendency of the fires to smoke, although there is still sometimes a down draught in the *unused* chimneys. The chimneys in regular use never smoke now. I consider it quite successful as far as it goes; but it would be much better with a larger stove and a larger pipe. I had nothing to guide me as regards the size of the pipe, except a few experiments by opening the back door $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ inch, and noting the effect, and the area of passage thus produced. In the coldest weather, the pipe admitted about as much air as the stove could take the chill off. If I were going to do it again, I should make the case to surround as much of the stove as possible, and make the pipe A much larger, say 10 inches, or with a larger stove 12 inches. I think it is the right principle to have a large free opening for air at the bottom of the house. This would stop the cold draughts in at windows, and prevent down draughts in flues and smoky chimneys. The air thus entering must have the chill taken off it, say 50° or 60°; and there should be apertures from the staircase (which is the air main) into the different rooms, that is, if the leakage round the doors is not enough. Perhaps the best plan would be, holes through the top of the door, (as in Fig. 2283,) with a shield to throw the air up if desired. If a

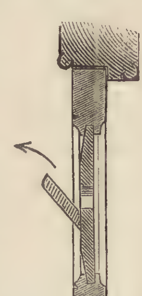


Fig. 2283.

room be supplied with air at 50°, a very small fire in the room will serve for comfort, and for carrying off the foul air. It might perhaps be thought that the warm air would all go up to the top of the house, but I find that the staircase is very considerably cooler at the upper part, and gets gradually warmer and warmer in descending from the top to the bottom. I have no doubt that a larger entrance-pipe for the air would send the heat up higher, but I have no fear of too much heat going to the top. With my 5-inch pipe, I have still both ascending and descending currents on the staircase, and I think this will always be the case.

"I had a good deal of trouble at first by the products of combustion from the stove coming back into the room round the iron plate, which was not built in. I found that this was owing to the flue of a copper in the washhouse entering the same chimney near the bottom, so that the air blew through the copper-flues, and down the chimney into the room. I made a wooden stopper covered with canvas, to fit the front of the copper-furnace, which effectually cured this defect."

Mr. William Griffin's cottager's stove appears to be judiciously arranged for the purposes of warming and ventilating. Fig. 2284 is an external elevation, and Fig. 2285 a vertical section. It is fitted with 2 ovens, or an oven and a hot-closet. "It comprises an open fire-place in the centre; a draw-shelf at the bottom of the grate; a drop-shelf at the top, which when raised, forms a blower; a hot-plate forming an ironing-stove; an opening at the top for the emission of warm air; an oven, hot-closet, damper, and sweep-door, and a boiler. In the flange of the oven and closet are slide-doors for the purpose of admitting a brush when sweeping is required." The oven has a flue all round it, and is equally heated. "When cooking is over, a fire made up of small coals, cinders, and ashes, well saturated with water, will last for several hours. The room is made agreeably warm by a continual supply of pure warm air drawn in from without through a drain or pipe to the hot-air chambers at the back and side of the fire-place, and emitted at the aperture at the top of the stove."

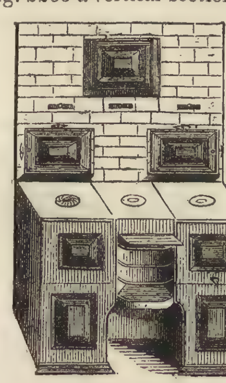


Fig. 2284.

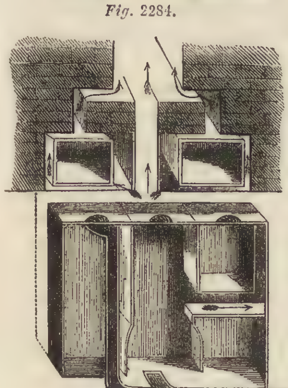


Fig. 2285.

In an interesting pamphlet by Mr. Francis Lloyd, recently published,[1] is described a warming and ventilating stove, constructed on the principle of the Polignac Stove (Figs. 2239—2243). In order to prevent the chimney from smoking, and at the same time to prevent draughts from doors and windows, Mr. Lloyd's first idea was to carry an air-tube from the external walls to the hearth-plate, to supply the fire with the air required for the combustion of the fuel. But as such a soufflet would interfere with the circulation of air in the room, it was proposed to construct caliducts also. "On examination, an ordinary register-stove showed that but a small proportion of the whole space allotted to it was occupied by the fire-grate, the frame around and above the grate forming a mere ornamental facing. There seemed to be no obstacle to substituting for this mere shell of cast-iron a horizontal and two upright tubes; and if they were connected with that beneath the hearth-plate, a continuous tube would be formed around the front of the fire. Air passing through these tubes would, it was imagined, acquire some warmth. The next consideration was, how to provide for the admission of the fresh air thus warmed into the room: and here it was important to select a place where the inflowing current should not be felt. The upper part of the mantel, from its proximity to the stove, and its position relatively to the occupants of the room, seemed a suitable place for the ingress of the air. Supposing the upper horizontal tube to have an opening or slit extending along the top throughout its whole length, the stove to be set sufficiently forward to leave this slit beyond the line of the chimney-breast, and the upper mantel and mantel-shelf to be so formed as to continue the passage-way from the tube, the air would be discharged into the room at about 4 feet above the level of the floor." This plan was adopted with success in the room of a house in town. A second and still more successful experiment is thus described by the author:—

"The dining-room of a house, a few miles from town, was rendered scarcely inhabitable in consequence of the chimney smoking. The room (which was about 16 feet square and 8 feet high) was on the ground-floor, with no basement story beneath. It was a few inches below the level of the garden in front, and had a provision for the circulation of air beneath the floor. The house was old, with doors and windows fitting but indifferently. The stove was of modern make; but the fire invariably burnt dull, and the room was scarcely ever well warmed. As the room was required for daily use by the family, alterations to the old stove would have caused inconvenience; a new register-stove, of the ordinary dining-room kind, was therefore selected, with the view of trying how such an one could be fitted with air-tubes. The *plan* of the new stove is shown in

(1) "Practical Remarks on the Warming, Ventilation, and Humidity of Rooms." 8vo. London, 1854.

Fig. 2286. To the cheeks and the back of the face, *a a*, of the stove were riveted two strips of sheet-iron bent in the form shown in Fig. 2287. The plan then appeared as in Fig. 2288. Two side-chambers or

Fig. 2286.

Fig. 2287.

Fig. 2288.

tubes, *b b*, being thus obtained, the back of the upper face of the stove was fitted with a rectangular tube, also of sheet-iron, which was connected with the two side tubes, making uninterrupted communication between them. The old stove was set very far back in the chimney shaft, and was fitted with a large marble mantel, the displacement or altering of which was, on many accounts, objectionable; it was therefore determined, in this instance, to admit the air into the room immediately under the mantelpiece, and afterwards to adopt means for preventing any inconvenient rush of air in a horizontal line into the room. The area of a section of each of the side tubes exceeded 18 inches, while that of the horizontal tube was about 40 inches. The width of the face of the stove was 3 feet; and to furnish the means for the admission of the air into the room, an opening of 1 inch in width was left at the top of the horizontal tube, in its vertical face, extending its whole length. A hearth-plate of cast-iron was then provided with openings corresponding to the horizontal section of the side tubes, as shown in the plan. The hearth-plate was then set with a chamber beneath, extending in the middle as far back as the line of the front fire-bars. From this chamber a zinc tube, 6 inches square, was carried under the marble hearth, beneath the floor, through the front wall into the garden, where it was carried up to the height of 14 inches, and was furnished with a cap having sides of finely perforated zinc. A passage-way of 36 inches area was thus obtained beneath, around, and above the *front* part of the stove, while there was a corresponding ingress for the air from the garden, and egress from the upper part of the stove into the room. The stove was set in the ordinary manner; and, within 24 hours of the removal of the old stove, a fire was lighted in the new one, and the room was in occupation. It was at once evident that the tendency to smoke was remedied, and the fire burnt freely and cheerfully. As it was felt to be an important point to introduce the air into the room in such a direction that its entrance should not be perceptible, the air-opening was furnished with a metal plate bent in such a form as would direct the air-stream towards the ceiling, and also admit of the supply being diminished, or stopped entirely, as might be found desirable. The complete and agreeable change in the character of the air of the room was at once apparent to every one; and, instead of the room being barely habitable, in cold weather it was found to be the most comfortable in the house. This stove was fixed at the latter end of December, 1850, and has been in use for four winters without the slightest difficulty of management, and with entire satisfaction to the inmates of the house. During the first winter careful observations were made on its action, and the results are in many respects remarkable. Within an hour after the fire is lighted the air issuing from the air-passages is found to be raised to a comfortable temperature; and it soon attains a heat of 80°, at which it can be maintained during the day with a moderate fire. The highest temperature that has been attained has been 95° whilst the lowest on cold days, with only a small fire, has been 70°. The result of twenty observations gave the following temperatures:—On two occasions, the temperature was 95°; the fire was large, and the door of the room was left open, so that the draught through the air-tubes was diminished; on five occasions, the temperature was below 80°, averaging 75°; the remaining thirteen gave an average of 80°. The mean temperature of the room at the level of respiration was 61°, while the uniformity was so perfect, that thermometers hanging on the three sides of the room rarely exhibited a greater difference than 1°, although two of the sides were external walls. As might be expected, there was no sensible draught from the door and window. On observing the relative temperatures of the inflowing and general air of the room, it appeared that there must be a regular current from the ceiling down to the lower part of the room, and thence to the fire. The inflowing current, being of a temperature nearly approximating to that of the body, was not easily detected by the hand; but, on being tried by the flame of a candle, it was observed to be very rapid, and to pursue a course nearly perpendicular towards the top of the room, widening as it ascended. It was also noticed, that the odour of dinner was imperceptible in a remarkably short time after the meal was concluded. In order to trace the course of the air with some exactitude, various expedients were made use of. It was felt to be a matter of great interest to ascertain, if possible, the direction of air respired by the lungs. The smoke of a cigar as discharged from the mouth has probably a temperature about the same as respired air, higher rather than lower, and was therefore assumed to be a satisfactory indicator. On its being repeatedly tried, it was observed that the smoke did not ascend to any great height in the room, but tended to form itself into a filmy cloud, at about 3 feet above the floor, at which level it maintained itself steadily, while it was gently wafted along the room to the fireplace. In order to get an abundant supply of visible smoke of a moderate temperature, a fumigator, charged with cut brown paper, was used. By this means a dense volume of smoke was obtained in a few seconds; and it conducted itself as in the last-mentioned experiment. On discharging smoke into the *inflowing air-current*, it was diffused so rapidly that its course could not be traced, but in a short time no smoke was observable in the room. Another experiment was made with a small balloon, charged with carburetted hydrogen gas, and balanced to the specific gravity of the air. On setting it at liberty near the air-opening, it was borne rapidly to the ceiling, near which it floated to one of the sides of the room, according to the part of the current in

which it was set free; it then invariably descended slowly, and made its way with a gentle motion towards the fire. The air has always felt fresh and agreeable, however many continuous hours the room may have been occupied, or however numerous the occupants. It is difficult to estimate the velocity of the inflowing current; but if it be assumed to be 10 feet per second, there would pass through the air-tubes in 12 minutes as much air as will equal the contents of the room. And as it appears that the air so admitted passes from the room in a continuous horizontal stream, carrying with it up the chimney the rarefied air, the exhalations from the persons present, the vitiated air from the lamps or candles, and all vapours rising from the table, it is by no means surprising that the air should always be refreshing and healthful. Since this stove has been fixed, others have elsewhere been fitted up on the same principle, and have been found to exhibit similar satisfactory results."

Figs. 2289, 2290 represent a horizontal and a vertical section of the tubular stove, in which a is a flue

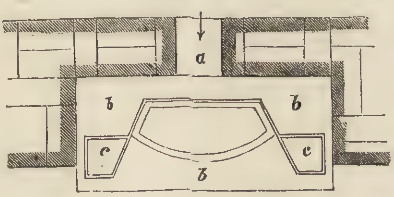


Fig. 2289.

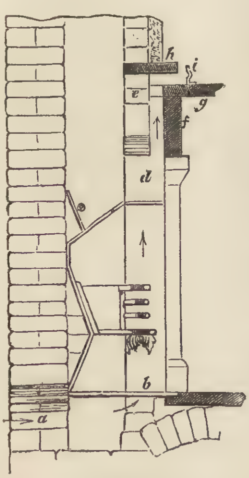


Fig. 2290.

6 × 9 inches, for conducting the external air from the outer wall to the under side of the hearth-plate b; $c\,c$ are openings in the hearth-plate b, communicating with two upright tubes of similar form, which conduct the air entering at a upwards to the horizontal tube d. This tube is fitted to the two upright tubes, and has an opening extending along its whole length. If the width of the stove be 3 feet, this opening should be $1\frac{1}{2}$ inch wide. The stove should be set $1\frac{3}{4}$ inch forward from the chimney-breast; f is the upper mantel, standing forward from the chimney-breast e $1\frac{1}{2}$ inch; g is the mantelshelf, with a portion of the back next the chimney-breast cut away in order to continue the air-passage; h is a thin slab of marble, $1\frac{1}{2}$ inch deep, built into the chimney-breast, and extending to the width of the mantel; it serves as a support for a chimney glass, and also to divert the current of air from flowing directly up the chimney-breast; i is a strip of metal or marble, which serves to guide the air-stream upwards. By moving i to h, the supply of air may be regulated; or i may be fixed, and a thin strip of metal fixed on centres at the extremities be placed between i and h, so as to act like a throttle-valve. The opening between i and h need not be more than 1 inch.

Mr. Lloyd also describes a domestic grate, which consumes its own smoke. It is circular in form, consisting of 4 circles (17 inches diameter) of bars, separated by pins, and fastened to an iron cross, which has a hole in the centre to admit a vertical spindle, to which the grate is firmly secured by means of keys above and below the cross. There is a hollow cylinder of iron or fire-clay, (5 inches diameter,) with a hemispherical top having a slit in it. This cylinder rests on the cross, and is as high as the top bar. The remaining part of the cross supports the usual grating for a stove, giving an area of 200 circular inches. There is an iron bar about 2 feet 6 inches long, with a coupling to embrace the spindle immediately below the fire-grate; also an iron hearth-plate, having a hollow boss to receive the end of the spindle. In setting the stove, the hearth-plate was so placed that the centre of the boss was $13\frac{1}{2}$ inches from the back wall. Brickwork was then carried up to the height of 1 foot 6 inches, and a depth of $13\frac{1}{2}$ inches, except in the centre, where a semicircle of 9 inches depth was formed, thereby making a niche of 18 inches in width. This was covered with a Welsh-lump, upon which brickwork was carried up square 2 feet 6 inches, and then sloped off to the chimney back. The end of the spindle was then placed in the boss, on the hearth-plate, and the iron bar secured in the brickwork. The coupling being secured, the circular grate now appeared one-half in the recess, the other projecting beyond the brickwork at the back, the Welsh-lump being about half-an-inch from the top, with its edge over the centre of the grate. The fire being lighted, and got up well in the whole circle of the grate, fresh coals were put on the front half, and the grate was turned half-round on its axis. A clear bright fire then appeared in front, while the gases and smoke from the fresh coals at the back made their way forward to the edge of the Welsh-lump, where they were subject to the heat of the clear front fire, aided by the stream of air passing up the hollow cylinder, which air, as it escaped by the slit, mixed with the smoke and gases, and assisted their combustion. When the front fire was burnt low, fresh fuel was put on, and the grate again turned half round. The fuel which had been at the back was then found to be coked, or to be giving off only a clear bright flame, according to the time that had elapsed since the fuel had been put on. On turning the stove round, so as to have the fresh fuel alternately at the back and front, it was evident that the arrangement secured the combustion of a large proportion of the smoke. This desirable end, therefore, is accomplished by the very simple operation of turning the grate half round, whenever any fresh fuel is put on. A clear, cheerful fire, with a semicircular face, well adapted to the radiation of heat, is thus

always presented to the room. For cottage use there would require to be some appendages to the bar, for the reception of trivets, kettles, and saucepans. These appendages would be placed over, but still be independent of the fire-grate. The arrangement also ensures the having at all times a clear bright fire, adapted to broiling or roasting."

Many years ago, Mr. Cutler invented a smoke-consuming grate, the principle of which was to supply the fuel at the bottom, so that the volatile portions, passing up through the incandescent fuel, were consumed. The mechanical arrangements of this grate were defective. Dr. Arnott has recently improved its construction with such success, as to claim for it the merits of a new invention. He has also effected certain other improvements, which may be easily added to the common grate. And, first, with respect to the consumption of smoke. The ordinary bottom of the grate being removed, the space is occupied by a *coal-box* with a solid movable bottom or piston, supported below by a vertical rack or ratchet-bar, held in position by a click, and capable of being raised through one or more notches by means of a lever or poker. In lighting the fire, the coal-box is to be first filled with bituminous coal. Upon this is placed paper and wood, and then the coked coal of the previous day's consumption. When this coke is kindled it ignites the top layer of coal in the coal-box. Fresh coal can then be brought up into the grate by raising the piston of the coal-box through a tooth or two of the rack. The smoke, ascending through the incandescent fuel, is of course consumed, and a large or a small fire may be had at pleasure, by raising with a poker the burning coal, so as to admit more air. An important adjunct to this arrangement is a conical hood placed over the fire, with a cylindrical pipe at the top, which passes into the chimney. A curved portion of the hood is cut away in front so as not to conceal any portion of the top of the fire. The effect of this hood is to contract the chimney to the dimensions of the cylindrical pipe at the top, so that the products of combustion only are discharged into the chimney shaft, instead of (as in ordinary cases) that large volume of air from the room which cools and dilutes the smoke, diminishes the draught, deprives the room of the larger portion of the heat of the fire, and leads to a wasteful expenditure of fuel. In cases where the Arnott ventilating valve is inoperative from this deficiency of draught, the simple addition of the hood is an effectual remedy, for no sooner is the hood adjusted to a badly drawing fire than the valve flies open, and a powerful ventilating current passes through it. The air required for the combustion of the coal is supplied by a ventiduct opening not immediately under the grate, as in the Polignac stove, but under the fender. The perfect, but economical combustion of the coal, in this arrangement, is shown by the fact, that no soot is deposited in the chimney, while the combustion is so slow that the fire will continue burning all night. In order to supply the coal-box with fresh fuel, a flat metal plate attached to a handle is slid in over the piston and under the burning fuel: the piston is then lowered to the bottom, the box filled with coals, and the plate withdrawn. The cylindrical portion of the hood is furnished with a throttle-valve, for regulating the draught at pleasure.[1]

WASH. See DISTILLATION.

WATCH. The going-part of clocks is sometimes termed the *watch-part*. Under the article HOROLOGY we alluded briefly to what are called *remontoire*, or *gravity escapements*. At the time when that article was written it could not be said that any of the numerous inventions of that class had been successful, although they have engaged the attention of the most scientific clockmakers, both professional and amateur, for nearly a century. It is important to observe the distinction between *train-remontoires* and *remontoire-escapements*. In the former, a scapewheel of the ordinary kind, or of any kind, is driven either by a small weight raised by the clock at intervals, of half a minute generally, or by a spiral spring on the scapewheel arbor, wound up a quarter or half a turn at those intervals; and at the same time the minute-hand moves with a visible jump, so that the time can be taken from it as exactly as from the seconds-hand of an astronomical clock.

This was the construction of the large clock with cast-iron wheels in the Great Exhibition, and now at the terminal station of the Great Northern Railway at King's Cross, London, for which the council medal was awarded to the late Mr. Dent; and its superiority to the gravity train-remontoires, which had been previously used in the best French turret-clocks, was so evident, that the present Mr. Dent (of the Strand) has introduced it, at his own expense, into the Royal Exchange clock in the place of the gravity remontoire with which that clock was originally made; and the friction is so much less, that only two-thirds of the former going weight is now required. A full description of it is given by Mr. Denison, who invented it, in his Treatise on Clocks, (page 240,) published in Weale's Rudimentary Series.

But although by means of a train-remontoire a constant force *on* the scape-wheel may be obtained, (for the variation of the force of the spring from temperature is far too small to affect a clock with a dead escapement,) the pendulum still remains subject to the variations of friction on the pallets; and, therefore, unless they are kept clean and well oiled, the force *of* the escapement cannot be regarded as constant; and the same necessity remains as before for delicate construction and high finish of the escapement itself. But in a paper in the Cambridge Philosophical Transactions of 1853, and in the 60th number of the Journal of the Society of Arts, Mr. Denison has described a new gravity-escapement invented by him, with the practical details found to be the most suitable for its construction after the experience of

(1) At the time when we are writing (March 1854), Dr. Arnott is preparing a pamphlet descriptive of this stove and other important matters connected with the art of warming and ventilation, which he has improved with so much scientific skill, inventive power, and liberality. We take this opportunity of expressing our respect for his truly patriotic exertions.

several clocks of different sizes in which it has been adopted, as he states, with complete success, and, with the approval of the Astronomer Royal, after severe trial of one of these clocks at Greenwich. The following is the substance of his description.

Fig. 2291 is the back elevation of an astronomical clock. The three-legged scapewheel is set near the bottom of the frame behind the back plate, with its back pivot in a cock: it has on its arbor a fly F F like a common striking fly between the plates, only larger, and a pinion of 8 driven by a wheel of 80 on the arbor which carries the seconds-hand. The rest of the train is the same as usual, only inverted in position, and there is no longer any occasion for the high-numbered pinions generally used in astronomical clocks, as the friction of the train is entirely cut off from the pendulum. A simple proof of this is, that doubling the clock weight produces no sensible effect on either the arc of the pendulum or the time. A heavier weight than usual is required, however, on account of the additional pinion and the fly. The pendulum is here represented as just leaving the right arm or pallet and taking up the other; and as soon as the stop S is drawn quite away from the tooth now resting on it,

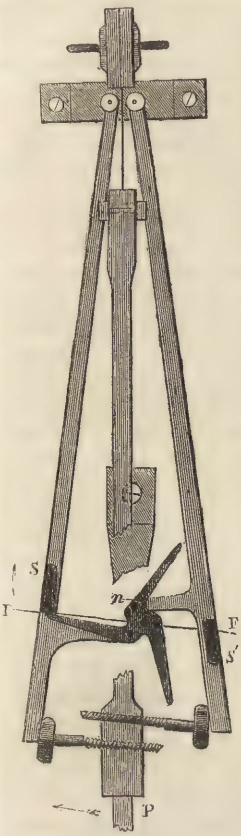


Fig. 2291.

the scapewheel will turn, and raise the other pallet by means of the pin *n*, which is now uppermost, until the tooth belonging to it is caught by the stop *s'* on that arm. If the arc at which the pendulum P leaves one pallet and takes up the other is called *c*, and the extreme arc *a*, each pallet ascends with the pendulum P from *c* to *a*, but descends with it not only to *c*, but to —*c* on the other side of zero; and consequently the pendulum receives an impulse from the weight of each arm alternately through the arc 2 *c*. The scapewheel evidently turns once round in 6 beats of the pendulum; and that gives a large enough motion at each beat for the fly to restrain its velocity, and thus prevent it from moving so fast as to jerk the pallet too far out, in which case the tooth may not be caught by the stop, and then the wheel runs on still faster, misses several beats, and perhaps breaks a tooth when it is caught by the stop descending again. This is called *tripping*, and has been the principal mechanical difficulty of gravity escapements.

Even those escapements which have been tolerably safe against actual tripping under any probable variation in the force of the clock train, have sometimes been liable to another miscarriage quite sufficient to injure the character of gravity escapements generally. Though the force of the scapewheel may not send the pallet so far as to let the tooth slip past the stop, it may send it further than it ought to go and would go if it were lifted more slowly, and then the pressure of the tooth on the stop is generally sufficient to hold it there; and the consequence is that the pendulum does not begin raising as soon as it ought to do, viz. at the arc *c* before-mentioned; and as the pallet will always descend with the pendulum to the same place, the impulse is increased, and the rate of the clock altered. In some of the gravity-escapement clocks in the Great Exhibition, you could sensibly increase the arc of the pendulum in a few minutes, by putting some extra force on the clock train; which showed that they failed in the very first essential of a gravity escapement. Here this is prevented by two things; first, by the fly, which moderates the velocity of the scapewheel; and, secondly, by the length of the locking teeth, the points of which are five or six times as far from the centre as the lifting pins, and therefore the pressure on the stop is so much less than where the lifting and the locking are both done by the same teeth, and is so little, that if an arm is by accident raised too high it will not stay there, but falls again, and the face of the pallet rests on the pin which lifted it, until the pendulum arrives and carries it off. The small amount of friction at unlocking also renders the pendulum indifferent to the absence or presence of oil on the stops, and they require none, except just enough to keep them from rusting. Everybody who knows anything of clockwork will recognise this as a point of primary importance in any improvement in escapements.

All other gravity escapements involve at least as much delicacy of construction as the finest dead escapement. This, on the contrary, requires so little that it is hardly possible for a workman intending to follow the rules given for its construction, to make it so that it will not act perfectly; and, consequently, in turret-clocks, besides the advantage of being able to use cast-iron wheels in the going part as well as the striking, there is no longer any occasion for long and heavy pendulums.

The distance of the points of the scapewheel teeth from the centre should not be much less than $\frac{1}{8}$th of the length of the arms (down to the stops): and the lifting pins should be $\frac{1}{30}$th of that length from the centre. The arc, before called *c*, will then be about 45′, or the pendulum will receive its impulse through 90′. The stops and the lifting faces of the pallets may be so adjusted as to make the depth of locking about $\frac{2}{3}$ds of the distance of the pins from the centre of the scapewheel, or (in round numbers) $\frac{1}{50}$th of the length of the arms. The arms should be only heavy enough to make the pendulum swing about 2° from zero. In astronomical clocks the length of the arms has generally been made 6 inches; in turret clocks, 9; but there is no particular virtue in these sizes.

The bend of the knee in the legs of the scapewheel is determined by the rule, that the pins and the points of the teeth alternately should lie on the radii of a regular hexagon. The stop on the pallet, which is struck upwards, must be set a little higher than the scapewheel centre, so that a straight line from there to the stop may form a right angle with the arm; for if the stop is lower than this, the blow will not be given in the direction of the arm, and will have a tendency to throw it outwards, which may as well be prevented, though it may not be enough to make the escapement trip. The other stop, however, should not be set so high as to form a right angle in the same way, because it will make the beats disagreeably unequal, and there is no occasion for it, as the action of the teeth on that stop, if set lower, is not to throw the arm out, but rather the contrary. The size of the fly in a regulator may be determined by trial. If you want a loud beat, you must have as small a fly as appears to be safe against any risk of tripping. In turret-clocks the fly should be not less than 5 inches long, by an inch broad, in each vane.

The scapewheel is made of steel not more than $\frac{1}{8}$th inch thick in a turret clock, and of course thinner in a regulator; the pins of brass wire, riveted in. The scapewheel of the great Westminster clock does not weigh half an ounce, although the pendulum weighs 6 cwt. The points of the teeth should be made tolerably hard, but not quite sharp. The stops should be screwed on soft, and adjusted to the proper depth of locking, and then made quite hard and polished; and the lifting faces of the pallets the same. The pallets of turret clocks may be of iron, only faced with steel: in astronomical clocks they can hardly be made light and stiff enough unless they are of steel, and not above $\frac{1}{16}$th of an inch thick. The lower ends are bent backwards at a right angle, to embrace the beat-screws in the pendulum, the action of which is obvious. It is better not to put oil, as to the common fork, on the points of contact, as there is no sensible friction, and it may tend to stick the fork pins to the beat-screws, and so resist the separation of the pendulum from the pallets; but the heads of the screws should be made of brass.

This escapement allows you always to set the clock right within one beat of the pendulum without touching it, by merely lifting one of the pallets and letting the scapewheel run forward, or turning it back, which will alter the time by any even number of beats you please: and the clock may be brought to exact time without touching the pendulum, by the following method:—

If the 10,000th part of the weight of a pendulum is stuck on to the rod half-way down its length, it will make the clock gain a little more than a second a day: that being the place where any given weight produces the *maximum* effect, and where any shifting of that weight up or down produces the *minimum* effect. Consequently, a sliding weight there is a bad way of regulating a pendulum; and on the other hand, if a collar is fixed there, and the pendulum so adjusted that it goes nearly right with some small weight laid on the collar, it can always have its rate altered by any assignable quantity, by merely altering that weight. The best way of making a series of weights for the purpose is to try the effect of some weight large enough to accelerate the clock a good many seconds a day; then you will know what any aliquot part of it will do; and from that knowledge make a series of weights in geometrical progression, marked $\frac{1}{4}$, $\frac{1}{2}$, 1, 2 (these will be quite enough), according to the number of seconds a day by which they will increase the rate when laid on the collar, and therefore diminish it when taken off; which can easily be done without disturbing the pendulum. One ounce will do a second a day in a pendulum of more than a quarter of a ton, and 10 grains in the common mercurial pendulum of an astronomical clock.

This escapement also, on account of its independence of all variations in the force and friction of the train, is well adapted for electrical clocks and dials; meaning by the former, clocks which wind themselves up by electricity, and by the latter, dials with the hands driven by electrical connexion with some standard clock at a distance, whether an electrical clock or not. A clock of this kind is easily made, as follows:— There is no great wheel or barrel; but on the centre wheel arbor there is a common spring-going ratchet (but with a weaker spring than usual) with 120 teeth. A lever is placed opposite to it, with a gathering click, so that when the lever is lifted by the temporary magnet at every half minute, the click drives or winds up the going ratchet the space of one tooth, and so of course the clock is kept going. The electrical contact may be made at every half minute, either as in Mr. Shepherd's clocks, described in article Horology, or perhaps better as follows: On the minute-wheel arbor put two half snails, so shaped and adjusted that a light lever which they raise may just drop on to the contact plate, connected with one of the battery wires, and be lifted off again at the next beat of the pendulum. By this means it is found that the contact can be made with great certainty at every 30th second, and allowed to last no longer than one second; and it is a contact without friction, which is almost essential to prevent oxydation of one of the points of contact, even if made of platinum, and it also consumes less force of the clock than a pin pressing against a spring for a few seconds. If the going ratchet is fixed to the arbor, the minute-hand will move by half-minute jumps; if the wheel is fixed, and the ratchet loose, the hand will move slowly as usual.

Where the hands of an electrical dial are to be driven by connexion with a standard clock, as they usually are, at half minutes, or even at every second, if they are large or exposed to the wind, it is found that the method of driving by pallets cannot be relied on; and a double ratchet-wheel with a gathering click, and backward and forward clicks, has been usually resorted to. But even this method cannot be depended on with certainty against the action of wind, which may either resist the motion of the hands at the critical moment, or drive the wheels on several teeth instead of one; and the adjustment of the two

ratchets is also a matter of some difficulty. Mr. Denison has therefore contrived a new arrangement of electrical dial-work, which he says is found to be safe against any pressure of the wheel, either backwards or forwards, at the moment of either making or breaking the electrical contact. In Fig. 2292, H is the wheel carrying the minute-hand, with 120 square teeth. When the contact is made, the magnet M raises the lever L E B into the position here represented, and with it the gathering or driving click A. The pin at B at the same time lifts the forward click B D out of

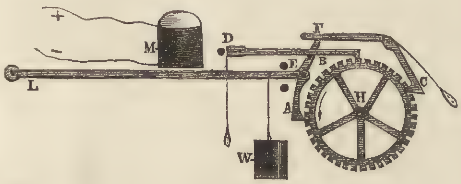


Fig. 2292.

the teeth, and the spring behind it makes it trip on to the top of a tooth, there being a little play left in the pivot-hole D for that purpose. The top of the lever is also made just to reach the tail of the backward click C F, when it is raised; so that when things are in this state it is evident that the wheel cannot be driven forward without pulling the lever away from the magnet, which no wind would be strong enough to do while the electrical circuit is complete; and as soon as it is broken, the lever ought to go, and will go, with or without the assistance of the wind, being pulled down by the weight W, till it rests on the banking-pin below it; and in so doing, the click A will drive the wheel one tooth, and the click B will drop into the tooth next to it, and be pushed back against its stop at D, and there stay till it is lifted again by the lever. Another advantage of this plan is, that the weight is always ready to pull away the lever from the magnet as soon as the magnet ceases to act, as it is certain to be enough to overcome the residual magnetism which sometimes prevents the lever from falling where the driving of the wheel is done directly by the magnet. Moreover, the wind cannot here prevent the lever from being lifted; if the magnet can ever lift the weight it always can; and even if the resistance of the wind should be too great for the weight at the moment of breaking contact, the weight is certain to have an opportunity of beating the wind before the next half-minute, and so a move can never be lost. It only remains to be added, that none of these arrangements are patented.

WATER, in chemical language, is called the *protoxide of hydrogen.* Its symbol is HO, and its equivalent number is 9. The relation which water bears to hydrogen, and the mode in which this gas may be obtained from it, are explained under HYDROGEN and OXYGEN.

Under the chemical properties of water may be included many qualities and uses which are not strictly chemical, but which are yet better noticed here than among mechanical or physical properties.

In its ordinary state as a liquid—neither so cold as to solidify, nor so heated as to vaporize—water is colourless, transparent, inodorous, and insipid. A cubic inch, at a temperature of 62° F. and at a barometric pressure of 30 inches, weighs 252·458 grains. As water furnishes the unit of specific gravity for all solids and liquids, and as atmospheric air furnishes the unit in respect to air, gases and vapours, it may be convenient to bear in mind that a cubic inch of atmospheric air, at the pressure and temperature above named, weighs 0·31 grains; and that therefore water is, bulk for bulk, about 815 times as heavy as air. Water is very slightly compressible, and is an imperfect conductor of heat and electricity. Water expands by heat and contracts by cold, like other substances; but it is subject to a singular exception in this respect, that it expands instead of contracting in descending from a temperature of about 40° F. to that of the freezing point, 32° F. Were it not for this property, ice would sink instead of floating in water, and lakes and rivers, and probably whole seas would become in winter masses of solid ice throughout. The remarkable properties of water when raised to so high a temperature as to vaporize, are explained under STEAM; and the application of those properties, under STEAM-ENGINE. Its properties under the solid form are noticed under HEAT and ICE.

Water possesses different qualities, according to the source whence it is obtained. Rain, dew, spring-water, river-water, well-water, lake-water, marsh-water, sea-water, mineral-water, all are affected in quality by the substances with which they have come in contact. The colour, taste, odour, and medicinal qualities, are all more or less likely to be influenced thereby. *Rain-water* is the purest of all except distilled water, although it contains minute portions of many acids and other substances which exist in the atmosphere through which it passes. It has high solvent powers, and is hence very valuable in cookery, and in chemical operations. [See RAIN-GAGE]. *Ice-water* is nearly destitute of atmospheric air; it is mawkish and insipid, and fishes cannot live in it. *Snow-water* is nearly allied in quality to ice-water; some persons think that it tends to produce the dreadful malady called *goître. Dew* differs principally from rain in possessing a little more atmospheric air. *Spring-water* derives its qualities from the strata through or over which it flows: if it take up chloride of sodium it becomes saline; if it take up salts of lime, it becomes what is called "hard;" if it imbibe carbonic acid, it becomes sparkling and pleasant to the taste; but the most valuable spring-water is that which is very nearly free from all these foreign substances. *River-water* may, in some respects, be regarded as a mixture of rain-water with spring-water; since it comprises a portion which has only flowed over the surface of the ground, and a portion which has percolated the strata beneath the surface. In most rivers, however, the quality of the water is more influenced by mud and detritus in the bed through which it flows than by any other circumstance; and hence the necessity of some mode of purification whenever river-water is adopted for the supply of

towns. [See FILTRATION.] *Well-water* being generally obtained from a deeper source than spring-water, is more likely to be affected by the mineral constituents of the soil. In the neighbourhood of London well-water or pump-water is always hard, and is very unfitted for washing, and culinary processes. It is a curious circumstance, however, that *Artesian well-water* is much softer, being brought up from a different kind of strata. [See ARTESIAN-WELL—BORING.] *Lake-water* partakes of characters intermediate between many of those above noticed: if the lake have no outlet, such as the Caspian and the Dead Sea, the water necessarily assumes a peculiar character from this circumstance. *Marsh-water* abounds in animal and vegetable matters, and is for the most part both unpleasant and unwholesome.

Sea-water contains many saline substances. The analysis of the water of the English Channel was given under SODIUM, *Chloride of.* M. Laurens found the water of the Mediterranean to contain as follows:—

Water	959·06
Chloride of Sodium	27·22
Chloride of Magnesium	6·14
Sulphate of Magnesia	7·02
Sulphate of Lime	0·15
Carbonate of Lime	0·09
Carbonate of Magnesia	0·11
Carbonic acid	0·20
Potash	0·01
	1000·00

Before such water can be fit for drinking, it is evident that the greater part of these saline ingredients must be removed. It has long been a desideratum to enable ships' crews to use sea-water for many culinary purposes, to obviate the necessity of taking out large supplies of fresh water. Many contrivances for this purpose have been invented; but the most effective is Mr. Grant's, by which the cooking of victuals and the purifying of water are carried on at the same time. The apparatus is called the "*Distilling and Cooking Galley.*" The galley contains the fires and vessels necessary for cooking. During the time when the fires are lighted, a portion of the heat is applied to the exterior of vessels containing sea-water; the water boils, and steam distils over, leaving the saline substances in the still. The steam condenses into nearly pure water, which is rather vapid through the absence of air or oxygen; but a little agitation, and access to open air, greatly lessens this defect. Most of the government ships are now provided with Grant's apparatus. Where steam-power is used on board, a ready means of distilling fresh water from salt is furnished.

Mineral-water is noticed under a separate article. See WATERS, MINERAL.

The various practical applications whereby the physical properties of water are rendered useful in the arts, are described under AQUEDUCT; FILTRATION; HYDROSTATICS AND HYDRODYNAMICS; PUMP; WATER-ENGINE; WATER-WHEELS; WATER-WORKS. The hydraulic action of the Archimedean Screw, and of the Screw-propeller, is noticed under STEAM NAVIGATION.

WATER-COLOURS. The materials used for water-colours do not differ much in respect to their general character, from those intended for oil-painting, except in comprising a larger number derived from the animal and vegetable kingdoms. Many of the salts produced by the combination of sulphuric, nitric, carbonic, muriatic, acetic, prussic, and other acids, with the oxides of iron, copper, tin, lead, zinc, mercury, and other metals, are sufficiently beautiful in colour to be employed as pigments; as are also some of the oxides and chlorides of those metals. According as the pigment is to be mixed with water, with size, with wax, or with oil, for different kinds of painting, so are there variations introduced in the mode of preparing them. Water-colours require more delicate treatment than any of the others in grinding, levigation, evaporation, drying, &c., to adapt them for the purposes of miniature painting. Liquid colours, too, for the use of map-colourers and others, require that the solid ingredients shall have dissolved completely in the liquid, to avoid the formation of any sediment.

The Council of the Society of Arts, willing to aid the labours of students in art, by providing them with good materials at a low price, recently offered a premium to any one who could manufacture a box of paints, comprising a small number of cakes of moderately good quality, which could be sold retail for one shilling. This, of course, was not intended so much to aid practised artists, as to afford cheap but useful aid to young students about to commence practice. A colour-maker in Bunhill Row succeeded in producing a shilling box of colours which met the requirements of the committee; and this neat little production is generally considered to be a remarkably cheap specimen of what can be done in this art.

There can be no doubt that improvements in chemistry ought to lead both to improvements in the quality and diminution in the price of colours and pigments. The artificial ultramarine is only one among many examples of really beautiful colours which are now produced as substitutes for others enormously expensive. Many of the reds, scarlets, crimsons, and carmines, are very expensive, in the particular tints which artists occasionally require; and it is a legitimate exercise of chemical research to find lower priced but equally useful substitutes for these. At the present time, an attempt is being made to apply electro-chemistry to colour making. It is known that when the acids and metals in a galvanic battery have performed their part, by assisting in the production of an electric current, the residue in the battery is generally reckoned of no account, and is abandoned. But this residue often consists of or comprises the very elements which constitute ordinary pigments. Hence, Dr. Watson has taken out a patent for a mode of making colours by electricity. He adopts a form of battery, and selects his materials, with a view to the production rather of a residue in the battery than of a current in the wire; the former being the end in view, and the latter a means to that end. The patent

is being worked by the "Electric Light, Colour and Power Company," who have established works for the purpose at Wandsworth; and also hope to be able to apply the electric power generated in the wire to a useful purpose, as well as the salts and other compounds generated in the battery. The colours thus produced are dry colours, in powder, or in lump—not ground in oil or in water like colours actually prepared for the artist.

Many kinds of water-colours are noticed under various headings, such as CARMINE—COBALT—COCHINEAL—ULTRAMARINE, &c.

WATER-ENGINE. This is an ingenious contrivance for obtaining motive power by the descent of a column of water. A water-wheel depends for its efficiency on a very slight descent of a large body of water; but the water-engine is more suitable for circumstances in which a small column of water descends from a considerable height. It is in mining operations that this machine appears most fitted to render useful service. At the silver-lead mine of Huelgoat, in Brittany, two water-engines of considerable size are employed. They are worked by a column of water descending from a height of 60 metres (about 200 feet). The power produced by this descent of water is applied to the working of a pump-rod; and the pump to which this rod belongs, brings up water from the vast depth of 230 metres (750 feet). Thus is afforded an instructive example of a mode in which one portion of water *descending* 200 feet, may cause another portion to *ascend* 750 feet. So well are the water-engines at Huelgoat constructed, that they are estimated to render available two-thirds of the power produced by the descent of the upper column of water.

In the "single-action water-engine" there is a piston which works up and down in a cylinder; the upward movement is occasioned by the pressure of water, and the downward movement by the weight of the piston and its connected metal work; whereas, in the "double-action water-engine," the piston is reciprocally acted on by water above and below. The water-engines set up by M. Juncker at Huelgoat are on the "single-action" principle. A piston moves vertically in a cylinder, which is connected near the bottom with a horizontal pipe bringing water from the descending column, and also with another pipe intended to carry away the water when it has exerted its action on the piston. When the admission-pipe allows the water to act on the lower surface of the piston in the cylinder, the piston becomes driven up to the top of the cylinder, and the piston-rod draws upward a pump-rod or any other mechanism with which it may be connected. As the cylinder is open at the top, the piston, pressed upon by the weight of the atmosphere, would have a tendency to descend; but this it cannot do until the water below it has been removed from the cylinder. This removal is effected by an ingenious subsidiary apparatus. Projecting from the top of the piston, and near one side of the cylinder, is a vertical rod with 2 cleats or studs; these studs catch against 2 cams outside the top of the cylinder—one stud lifting one cam during the ascent of the piston; and the other stud drawing down the other cam during the descent of the piston. These cams are at the two ends of a circular arc, connected by intervening leverage with a small vertical piston-rod; and the whole arrangement is such that, when the large piston rises, the small piston-rod rises also. This small rod has 2 pistons which work in a small vertical tube, and alternately open and shut the mouths of 2 horizontal tubes. These horizontal tubes are connected, the one with the admission-pipe and the other with the discharge-pipe. The end and object of these subsidiary arrangements are, that when the piston has been driven up to the top of the large cylinder, the connexion with the supply-pipe becomes closed, the connexion with the discharge-pipe becomes opened, the water flows out of the cylinder, and the piston descends. A reversal of all these conditions causes a re-ascent of the cylinder; and thus a reciprocal action is kept up, well fitted for working a pump-rod.

The mechanism of this single-action engine is intricate. Those who wish to study it in detail will find it well described, and well illustrated by engravings, by M. Delaunay.[1] We will proceed to describe the "double-action water-engine," which is more easily illustrated and comprehended.

The double-action engine differs from the single-action chiefly in these two particulars—that the cylinder is closed at the top as well as at the bottom, and that there are two supply-pipes, at the top and bottom of the cylinder respectively. The piston P,

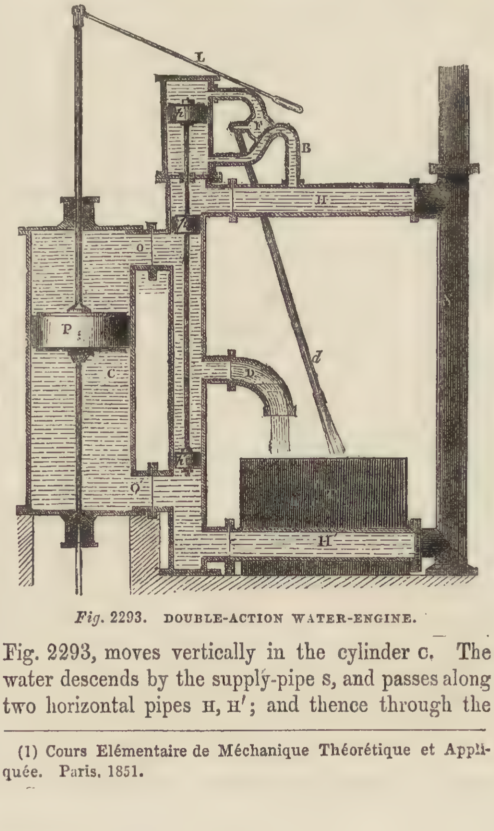


Fig. 2293. DOUBLE-ACTION WATER-ENGINE.

Fig. 2293, moves vertically in the cylinder C. The water descends by the supply-pipe S, and passes along two horizontal pipes H, H'; and thence through the

(1) Cours Elémentaire de Méchanique Théorétique et Appliquée. Paris, 1851.

two openings O, O′, into the cylinder. Two pistons p, p', fixed on the same rod, move vertically in a small cylinder placed by the side of a larger cylinder. In the actual position represented in the engraving, the water can pass through the lower horizontal pipe H′, and through the lower opening O′, into the space beneath the piston in the large cylinder; it hence exerts an upward force, sufficient to drive the piston to the top of the cylinder. But there is water resting on the piston also, and it is necessary that this water should be removed in order that the piston may ascend. This water, it will be seen, has a free communication by the upper opening O with the discharge-pipe D. The piston, being pressed forcibly from beneath, rises, and drives out the water from above it into the waste tank T. If, at the moment when the piston attains its greatest height in the cylinder, the two small pistons p, p' were lowered so as to come respectively beneath the openings O, O′, it is evident that the upper opening O would communicate with the upper supply-pipe S; while the lower opening O′ would communicate with the discharge-pipe D. The pressure would then cause the piston to descend, and the water beneath the piston would flow out of the cylinder through O′ and D. Now, to bring about this action of the two small pistons p, p', the mechanism at the top of the engine has been contrived. The up and down movement of the rod to which these two pistons are attached is produced by means of another piston p'' adapted to the upper end of the rod; it moves in a cylinder of its own. A four-way cock, F, opens a double communication between this small upper cylinder and the upper supply-pipe on the one hand, and with the discharge-pipe on the other. In the position indicated in the engraving, the supply-water passes from S through the bent pipe B into the small cylinder, and forces up the small piston p'': while the water which is above this little piston finds an outlet by the smaller discharge-pipe *d*. If the four-way cock be turned one quarter round, the water obtains access to the upper surface of the small piston, pressing it downward, while the water beneath the piston finds its way to the small discharge-pipe. Whenever the small upper piston p'' descends, it causes the descent of the other two small pistons, p, p'; and these regulate the admission of water into, and the discharge of water from, the larger cylinder. The movements of the four-way cock are governed by the lever L, which is itself governed by the ascending and descending movements of the piston-rod in the large cylinder. The whole machine thereby becomes self-regulating.

The water-engine is most likely to be valued in countries where steam-power, through the high cost of coal, is not much adopted.

WATER-WHEELS. Among the modes in which a stream of flowing water is made available as a source of mechanical power, the *water-wheel* is one of the most familiar. In all forms of the machine, the water is in considerable volume, with only a small descent; the axis of the wheel is generally horizontal, but in some varieties it is vertical. The chief kinds of water-wheel are *undershot* wheels, *overshot* wheels, *breast* wheels, and *horizontal* wheels, varying chiefly in the point at which the water impinges upon the periphery of the wheel.

An *undershot* wheel (Fig. 2294) has a number of float-boards F *f f* or plane-surfaces ranged round its circumference, so shaped and placed that the water may fall upon them, and may by its pressure cause the wheel to rotate on its axis W. The water is brought by an inclined canal or channel C to the lower part of the wheel. The wheel is here represented with 24 float-boards; but it may have any greater or lesser number. It is evident, from the direction in which the water approaches the float-board F, that a force will be produced tending to rotate the wheel; and as each float-board comes in succession into that position, the force is virtually continuous.

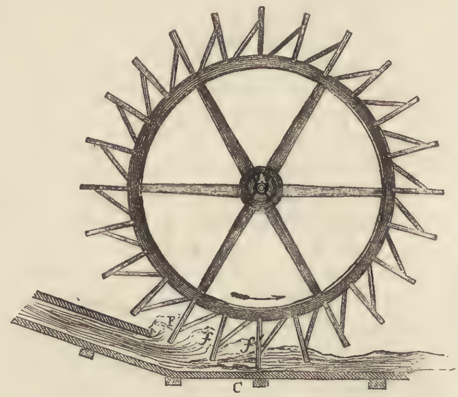


Fig. 2294. UNDERSHOT WHEEL.

In the *overshot* wheel, Fig. 2295, the construction and action are somewhat more complex, and afford more scope for the exercise of the engineer's judgment. The wheel L R has a number of buckets B *b b′* instead of float-boards, ranged round its circumference. When the water flows along the channel C to the bucket *b*, it tends to put the wheel in motion; if this bucket were exactly over the axis W, the wheel would neither tend in one direction nor the other; but the bucket being on one side of a vertical line passing through the axis, a leverage is obtained represented by the distance *b* W, being the horizontal

Fig. 2295. OVERSHOT WHEEL.

distance from the axis to a vertical line B *b* passing through the centre of the bucket. When the bucket, by the motion of the wheel, comes into the position *b' b'*, the leverage is increased from *b* W to *b'* W, and the mechanical effect is increased. This increase continues until the bucket arrives at the extreme right R of the wheel, after which it decreases. There is a further decrease also, due to the flowing of the water out of the bucket. It is plain that much of the efficacy of the machine depends upon the power of the bucket to retain the water until it reaches near the bottom of the wheel; the form shown in the engraving (to illustrate the principle) is very defective; the water begins to flow out at R, whereas, with a better form of bucket, a greater power of retention might be ensured. The water ought not to begin to flow out until the bucket has passed the point of greatest leverage at R; and it ought not to have completely flowed out until the bucket has arrived nearly at the bottom. The variations adopted by engineers in overshot water-wheels are numerous, on account of the influence exerted by the number, shape, and arrangement of the buckets.

A *breast* wheel, Fig. 2296, presents its axis almost on a level with the surface of the water. The wheel, R L, has float-boards instead of buckets. The water approaches by the channel C, and falls upon or against

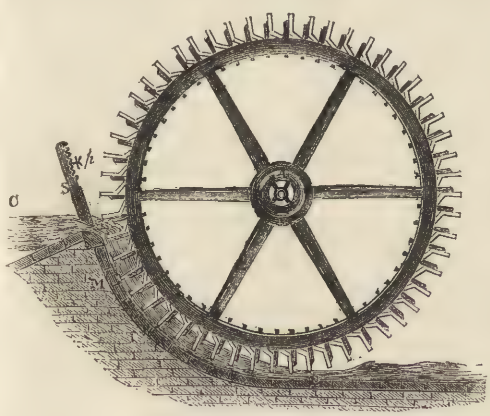


Fig. 2296. BREAST WHEEL.

the float-board *b;* engineers differ in plan, some placing this point of contact a little above, and others a little below the level of the axis A. The mill course M is a channel accurately fitted to the curve formed by the ends of all the float-boards; so that the space between any two boards forms a kind of box, which retains the water until the board has arrived near the lowest point. There is a sluice or shuttle S, moved by a pinion P, to regulate the quantity of water admitted to act upon the wheel.

The *horizontal* wheel, Fig. 2297, is occasionally employed where a vertical axis of motion is required, as a means of producing it without much loss of power. A mill-stone is frequently moved in this manner. The horizontal wheel differs little from the undershot wheel except in the direction of the axis; the mill-course and the float-boards are nearly alike in both. The water-course, first oblique, is made nearly horizontal, by the time the water impinges upon the float-board. In some forms of construction the floats are in radial lines from the axis A, while in others

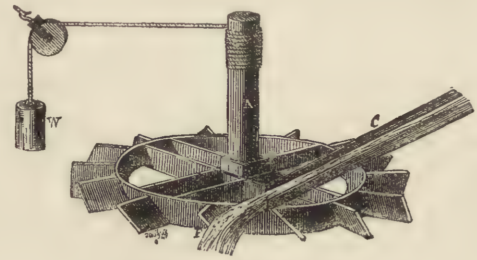


Fig. 2297. HORIZONTAL WHEEL.

they are oblique to the radii: where this obliquity is very considerable, the water is not turned into a horizontal course, but descends from C to the float-board F, and thus causes the wheel to rotate.

It is demonstrable, by the theory of hydrodynamics, that if the velocity of the steam be given, the effect on any of the wheels will be as the water expended; that if the expenditure of water be given, the effect will be as the square of the velocity; and that the efficacy of an overshot wheel is to that of an undershot wheel—the weight of water, the aperture, and the diameter being given—as 13 to 5 nearly.

WATER-WORKS. In the articles AQUEDUCT and FILTRATION many details will be found relating to the supply of water to large towns. In the present article a few additional matters will be treated, relating to the metropolitan supply.

Before the time of Sir Hugh Myddleton, London was partly supplied with water by springs. There were public reservoirs in the city; and to these reservoirs conduits or pipes were brought from Tyburn in 1236, from Highbury in 1438, from Hackney in 1535, from Hampstead in 1543, and from Hoxton in 1546. Water-works were formed at London Bridge in 1582, with water-wheels turned by the ebb and flow of the river. Until these works were constructed, no houses were supplied direct by pipes; for the inhabitants were dependent on water-carriers, who brought the water in carts from the conduits and reservoirs. In 1613 Sir Hugh Myddleton brought to a completion his great undertaking of conducting the water of the New River to London, and conducting branch-pipes from the New River Head or Reservoir to the houses of the consumers. It is too late now to inquire whether such a large undertaking as supplying a city with water should be managed by joint-stock companies or by the government; the example set by Myddleton's Company has been followed; other companies have been formed from time to time; and London has ever since been supplied with water by companies only.

During the inquiries made by the Board of Health relating to the London Water-supply, in 1850 and 1851, the respective companies were required to make a return of the expenses which they incurred for every million gallons of water supplied. Their returns were as follow:—

	£	s.	d.
New River	9	17	4
East London	6	7	7½
Southwark	5	9	4
West Middlesex	16	9	7
Lambeth	15	0	6½
Chelsea	19	10	4½
Grand Junction	9	14	6½
Kent	17	2	10½
Hampstead	22	5	7½
Average, about	£10	10	10

The difference between the Hampstead and the Southwark Companies is here remarkably great. It was at the same time estimated that the average charge to the public was about 25*l.* per million gallons, leaving about ⅘ths of the gross receipts to pay interest on the capital expended.

The sources whence these companies obtain their supply are as follow:—The *New River Company*, from the Lea River and adjacent springs, and from four deep wells sunk into the chalk. The *East London Company*, from the Lea near Old Ford. The *Kent Company*, from the Ravensbourne below Lewisham. The *Hampstead Company*, from springs near Hampstead, and from two Artesian wells. The *Lambeth Company*, from the Thames at Thames Ditton. The *Chelsea Company*, from the Thames near Chelsea. The *Southwark and Vauxhall Company*, from the Thames near Battersea; the *West Middlesex Company*, from the Thames near Barnes; and the *Grand Junction Company*, from the Thames near Kew Bridge.

In 1850 the various companies supplied the following quantities:—The New River Company supplied 83,206 tenements with 5,278 million gallons, or 174 gallons per house per day. The *East* London Company supplied 56,679 tenements with 2,956 million gallons, or 143 gallons per house per day. The Southwark Company supplied 34,864 tenements with 1,820 million gallons, or 143 gallons per house per day. The West Middlesex Company supplied 24,480 tenements with 1,109 million gallons, or 124 gallons per house per day. The Lambeth Company supplied 23,396 tenements with 913 million gallons, or 107 gallons per house per day. The Chelsea Company supplied 20,996 tenements with 1,304 million gallons, or 170 gallons per house per day. The Grand Junction Company supplied 14,058 tenements with 1,127 million gallons, or 220 gallons per house per day. The Kent Company supplied 9,632 tenements with 323 million gallons, or 98 gallons per house per day. The Hampstead Company supplied 4,490 tenements with 146 million gallons, or 89 gallons per house per day. It may be assumed that, where the supply per house is small, the houses in that district are generally of a humble character. In the aggregate, 271,794 tenements were supplied with 140 gallons each per day on an average. The total supply furnished by all the nine companies, including tenements, large establishments, street watering, flushing-sewers, and fires, amounted to 16,748 million gallons in the year.

During the last thirty years discussions have been carried on concerning the necessity of obtaining a better quality and a larger quantity of water for London, and concerning the source whence it can be obtained. Some engineers and medical inquirers have advocated a supply from the Thames, high up in its course; some have advocated the Colne and other rivers, which flow into the Thames from Hertfordshire; some have proposed to use the catch-water from a large barren district near Bagshot; while others have advocated the boring of artesian wells. The opinions on all these points are very conflicting; and the want of unanimity on the part of engineers and medical men seems to have brought the whole affair to a stand-still, so far as new projects are concerned. The existing water-companies, alarmed at the many new schemes which threatened them, offered to make great improvements; most of them obtained special Acts of Parliament in 1852, for establishing new sources of supply, (either in the Thames or the Lea,) for filtering the water, and for reducing the charge made to the public. These improvements are now being carried out. The projectors of a new Water-Company sought, in 1852 and in 1853, to obtain an Act of Parliament; but the legislature has deemed it right to give the old companies an opportunity of making their proposed reforms, before offering encouragement to a rival. The metropolis remains in 1854, therefore, dependent for water-supply on the same nine companies which commanded the supply ten or fifteen years ago.

The hydrodynamic principles on which modern water-works are conducted are easy of description. The ancients did not adopt the principle of pressure whereby water will find the same level at the two ends of a continuous pipe, however much the pipe may dip at the centre; they were acquainted with the principle, but they were deficient in the means of providing large pipes of sufficient strength; and they adopted the *aqueduct* principle instead. In modern water-works, when the source of supply is situated at a higher point than any of the buildings to be supplied, reservoirs are formed to retain a body of water always in readiness; main-pipes descend thence to the streets, service-pipes extend to the houses, and cisterns and ball-cocks regulate the supply of water, and prevent waste. Where the source of supply is lower than the level of the streets and houses, as where the water is obtained from a river, a different plan must be acted on. The most usual course, in such case, is to construct one or more reservoirs at a suitable elevation, and to supply them with water through ascending pipes or mains by means of force-pumps, worked by steam-power or water-power. Provided the reservoirs so formed are sufficiently elevated, the water may be made to flow from them to the houses just as if the actual source of supply were at that elevation. Sometimes it is necessary to supply houses at a greater elevation than the highest reservoir; this object is usually effected by employing a pumping-engine to propel the water from the reservoir along the pipes which lie too high to be filled in the ordinary way. To prevent the danger which might arise from the application of too great a pressure by the pumping-engine, a vertical pipe is usually connected with the pipes for the high delivery, and

J. C. Armytage.

carried up to an elevation equal to that of the highest point to be supplied; such a pipe, which may be erected in the reservoir, and left open at the top, or turned downwards again in the form of a syphon, acts as a sort of safety-valve. In some cases, as at the Hyde Park Reservoir, the lofty pipes or syphons are superseded by safety-valves loaded to a degree equal to the pressure of the required column of water.

The old water-pipes of London were principally of wood, formed of whole trunks of trees bored by machinery. Stone-ware pipes and coarse glass pipes have been proposed as substitutes for the old wooden pipes; but the only effective improvement has been in the use of cast-iron. All the London water-companies now use cast-iron mains to convey the water beneath the streets, leaving the builders to employ small lead-pipes to convey the water to the houses.

In the reservoirs of the several companies much careful engineering is required. The sluices, valves, and various outlets, often call for much carefulness of treatment. The East London Water-works are provided with *balance-gates* of remarkable character. In 1833 the company made considerable alterations and additions to their works. They cut a canal for the purpose of bringing the water from a higher part of the river Lea, near the Lea Bridge Mills, to their works at Old Ford. To guard against any deficiency of water for working the various mills on the Lea, the company formed a large compensating reservoir, covering 14 or 15 acres of land. This reservoir has two entrances, one near Old Ford Lock, and another above City Mill Point. At the former of these entrances is constructed a pair of tide or flood-gates, for the *admission* of water only as the tide rises; while at the latter there are three openings with six balance-gates, for the *admission* of water from the river Lea, and for *discharging* the water out of the reservoir into the river for the use of the millers. As the tide flows up the river it fills the reservoirs; and when the tide ebbs, if required by the millers, the water is allowed to run out into the river. Mr. Wicksteed devised a new kind of balance-gate for this second opening. As the neap-tides at the point of delivery rise, on some occasions, only a few inches, and as consequently a very large body of water might have to be delivered within a short space of time, with so low a head or pressure, a great width of outlet became necessary; if the ordinary sluice-gates had been erected, the time required to open them would have been above an hour and a half, and consequently the whole of the water might not have been returned into the river before the preceding low-water. Mr. Wicksteed has so contrived his balance-gates that they can be opened or closed in ten minutes, against a pressure of water. There are six balance-gates in three openings; but a description of one gate will suffice for all. The gate is made to work upon a vertical shaft as a centre. One gate, when closed, works against another gate on one side, while the opposite sides close against a recess in the piers or side-walls. Whatever pressure of water may be against the gates, there is as great a tendency to keep the gate closed as to open it, on account of the two halves moving in opposite directions round a centre; a very slight exertion of power, therefore, will either open or close them. When the gates are closed, and the water is to be retained in the reservoirs, these eccentrics, working upon a shaft, pinch the gates against their abutments, and thus prevent any leakage; but when the gates are to be opened, and the water discharged, the eccentrics are loosened from their hold, and a small exertion of manual force, by means of a pinion and toothed quadrant, suffices to open the gates.

WATERING OF STUFFS. See CALENDERING.

WATERPROOFING is the art of making cloth and textile fabrics in general impervious to moisture. The purposes are very numerous, in the arts, to which waterproof cloth is now applied. There ought, in strictness, to be some other term employed, for most of the varieties are airproof as well as waterproof; the ordinary expression, however, is sufficiently well understood.

The cloth, whether of silk, cotton, flax, or wool, is usually rendered waterproof by the application of some solution to one or both surfaces. Leather occasionally undergoes an analogous process of treatment, but not so frequently as cloth. In many of the earlier modes of procedure, the cloth was immersed in a liquid, so as to become saturated with the waterproofing agent. Mr. Hellewell's patent, in 1835, was of this kind; it bore relation to a composition of rock-alum and whiting in water, in which the cloth was dipped, and to a subsequent application of soap and water. A patent by Mr. Hall, of Doncaster, in 1839, specified two solutions; one consisting of alum, white-lead, and water; and the other of alum, whitelead, acetic acid, and water; the cloth, after being steeped in one or other of these solutions, is passed through a solution of quicklime, and then through a solution of boiled moss. These are only two among many patented methods which, whether effective or not, have been superseded by better plans.

By far the greater number of methods relate to a surface-application of some composition which is generally somewhat thicker than a mere liquid solution. The use of tar for tarpaulins, and of oil for oilskin, are familiar examples. One of many kinds of varnish employed for this purpose consists of linseed-oil, pipeclay, burnt umber, whitelead, and pounded pumice-stone; it is applied as a protective to tarpaulins, awnings, coach-covers, boat-cloaks, &c. In 1840, a patent was obtained by Mr. Newberg, for a mode of rendering cloth waterproof without concealing its textile surface:—the cloth is in the first place saturated with a waterproof composition; it is then dried on one side to form a hard film; while the other side is kept moist, and is afterwards deprived of its composition by means of spirits of turpentine.

But the modes of applying caoutchouc or india-rubber for this purpose have given greatly increased importance to waterproof fabrics. The process of manufacturing mackintosh cloth, already described under CAOUTCHOUC, will serve to convey a general idea of waterproofing as effected through the agency

of this remarkable gum. It will suffice, therefore, simply to enumerate the variety of articles now made of waterproof cloth. The life-garments, life-belts, life-buoys, and life-boats, made or covered with india-rubber cloth, are numerous and ingenious. A safety-boat has been invented, formed of a sort of canvas bag impregnated with liquid india-rubber. Another safety-boat has a framework of cork, and a covering of india-rubber canvas. A third kind, tried some years ago in France, consists of a skeleton framework, each part of which is covered with india-rubber cloth, and is provided with hinges. A boat about a hundred feet long, loaded with nearly a hundred tons of wine and wood, was safely navigated from Auxerre to Paris; it was then taken to pieces in a few minutes, and was conveyed back to Auxerre in two carts—a remarkable proof of lightness of construction. Macintosh's "life-cape" is made of a double thickness of india-rubber cloth, with apparatus for forcing air into the interstice between the two layers. "Yachting-jackets" are made in a similar way. Beds, hammocks, mattresses, cushions, and pillows, are made in great variety, by different modes of applying the india-rubber cloth. Dr. Arnott's "water-bed," or "hydrostatic-bed," is a happy application of waterproof cloth, as an envelope or covering for a space intended to contain water. At the Great Exhibition, the uses of waterproof cloth were fully and curiously illustrated. There were umbrella-tents, portable boats for lake fishing and duck shooting, portable baths, boat-cloaks which were susceptible of conversion into cloak-boats, boots and shoes, surgical and chemical apparatus.

Many compositions have been proposed, and some of them patented, for rendering leather waterproof, by filling up the minute pores. Four or five may be briefly described, as examples of the whole. Boiled linseed-oil, mutton-suet, yellow bees-wax, and common resin, are melted over a slow fire, and applied while hot to the leather, which is itself to be made slightly warm. Linseed-oil, resin, white vitriol, spirit of turpentine, and white oak sawdust, are the materials of another composition. Yellow bees-wax, Burgundy pitch, turpentine, and linseed-oil, constitute a third. A fourth plan consists in applying to the leather a hot mixture of two parts tallow with one part resin. Another proposal is to apply a coating of tallow to the leather, and a second coating of one part copaiba balsam with two of naphtha. The last composition which we shall mention consists of caoutchouc, boiled for two hours in linseed or neat's-foot oil.

WATERS, MINERAL. Mineral waters derive their distinctive characters from the formations or strata through which they flow. Those of the primitive formations are almost all thermal, and generally possess a high temperature. Those of the older secondary formations are generally of a lower temperature. The newer, secondary, and the tertiary strata, give forth cool mineral waters. The chemical contents —sulphuretted hydrogen, free carbonic acid, carbonate of soda, other salts of soda and of lime, silica, sulphate of magnesia, oxide of iron, free sulphuric and muriatic acids—vary in almost every individual case; but there is a general tendency in mineral waters from the primary formations to a sort of similarity of chemical contents, and so likewise in respect to the secondary and tertiary formations.

Leaving out *thermal* waters, which are not designated mineral waters unless for some additional quality besides their high temperature, mineral waters are often classed into *saline, alkaline, chalybeate,* and *sulphureous.* Most of the celebrated Spas belong to one or other of these four classes,—the Cheltenham, Leamington, Harrogate, Carlsbad, Marienbad, Kissingen, Wiesbaden, Seidlitz, and Baden. Baden waters are saline-aperient, some hot and some cold; or, rather, it should be said that *some* of the springs at these places are saline-aperient; for there are other springs at the same towns possessing very different qualities. Alkaline waters are met with at Bath, Cheltenham, Leamington, Harrogate, Scarborough, Carlsbad, Marienbad, Kissingen, Töplitz, Wiesbaden, Vichy, and many other places. Among the places at which chalybeate waters, or water in which the iron is associated with much free carbonic-acid gas, are met with, are Tonbridge, Harrogate, Brighton, Peterhead, Aix-la-Chapelle, Spa, Pyrmont, Schwalbach, Marienbad, and Seltzer. Sulphureous waters are found at Moffat, Askern, Harrogate, Aix-la-Chapelle, and other places. It will be seen that Harrogate possesses a large variety of these mineralized waters. A small number of springs contain iodine, and are on that account useful in certain maladies. There are springs of this kind at Tewkesbury, Cheltenham, Gloucester, Leamington, Builth, Llandrindod, and Kreuznach. Some others contain a little bromine, and a few contain both iodine and bromine.

Soda-water belongs to a large class of aerated waters, comprising beverages artificially produced, and having for the most part an effervescing quality. Soda-water is, indeed, the principal of these; but there are many different kinds, some intended to imitate mineral waters, such as Seltzer-water, Pyrmont-water, &c. In all such manufactured drinks, certain powders are placed in a vessel, where they are acted upon by water; a chemical action ensues, which produces a beverage depending on the nature of the powders. The materials for soda-water are carbonate of soda and tartaric-acid; but other salts and acids are employed in other instances, varying according to the kind of beverage required.

An elegant little apparatus, Fig. 2298, has been brought into use within the last few years, patented by M. Mathieu as an improvement upon an earlier invention. It is calculated for the preparation of aerated beverages in private houses rather than for sale, since it can yield but a small quantity at a time. There are two oval glass vessels, the larger one placed vertically over the smaller. There is a passage of communication from the one to the other, and in this passage is a cock for drawing off the aerated liquid. The upper or larger glass is filled with water, by removing the cover; and the lower or smaller glass is supplied with the pow-

ders. These powders are, as in other cases, of different kinds, according to the sort of beverage to be produced. A small pipe descends from nearly the top of the upper vessel to nearly the bottom of the lower,

Fig. 2298.

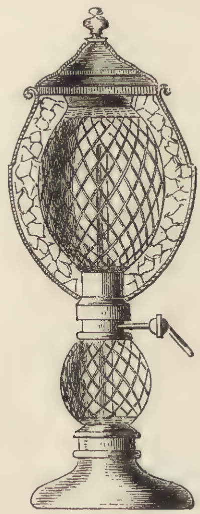


Fig. 2299.

a little water descends through this pipe, mixes with the powder, and produces gases; and these gases ascend to the water in the upper vessel. Of course, such gases only as are soluble in water are generated. The gas chiefly used is carbonic acid, of which water will absorb its own bulk, and by pressure can be made to take up another volume. [See Carbonic Acid.] As the gas accumulates in the upper vessel, the pressure increases, and the water is thus enabled to take up its additional supply. The two vessels are generally surrounded with a netting of wire or cane, for security. In the simpler forms of the apparatus, nothing further presents itself; but in M. Mathieu's improvement, there is a refrigerating contrivance. In Fig. 2299, a view of this improved form is given. The upper vessel is surrounded by an external shell and sheath, so as to leave an intervening space; and into this space may be introduced either ice or cold water, or freezing mixture.

MM. Gaillard and Dubois' *Gazogene,* or aerated water apparatus, is a much more complicated contrivance. It contains three distinct chambers or vessels, one for the water to be aerated, one for the effervescing powders, and one to contain a small quantity of water which is to act upon the powders. It is necessary to separate all three vessels, when the apparatus is to be prepared for use; and this is one cause of its complexity. When all three have been properly supplied, the finger is pressed upon a stud or button at the top of the apparatus. This pressure opens a valve which allows the water in the small upper vessel to descend into the vessel containing the powders. The gas, thus generated, can only escape from the powder-vessel by descending a small tube which dips into the larger vessel; and the water with which this larger vessel is nearly filled becomes impregnated with the gas. A second finger-stud governs the valve of a small pipe which enables the aerated water to flow from the apparatus. The apparatus is elegant in construction, but it has not the elegance of simplicity.

Fig. 2300.

Mr. Masters's aerating machine is similar in principle to Mathieu's, though differing in details. The powders are placed in the lower part of the apparatus, and the water in the upper; a little water descends to the powders, and the generating gas rises. A stud, acted upon by the thumb, draws off the beverage when wanted. Fig. 2300 represents one among many forms of this pretty apparatus.

Fig. 2301 represents Messrs. Tyler, Hayward and Co.'s patent double soda-water machine; it is adapted for bottles, and can make 300 dozen per day. There

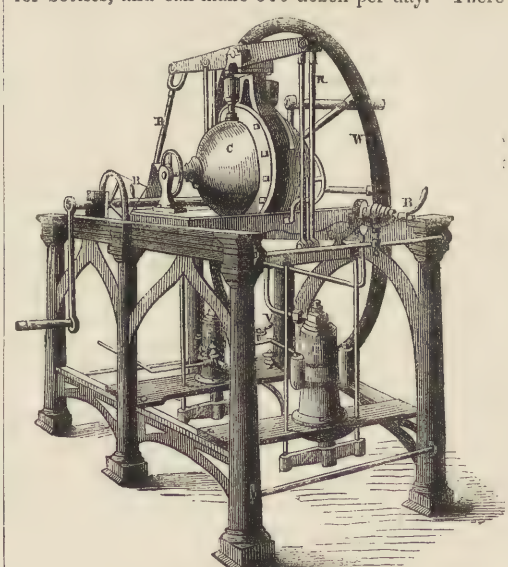


Fig. 2301. SODA-WATER ENGINE.

are two distinct machines in one frame, which can be worked together or separate. The generator and gasholder are not represented in the cut. C is a condenser, divided into two by a partition inside. Each half has an agitator, worked by the wheel W. P P are two condensing pumps, with regulating cocks for admitting aerated water. B B are bottling cocks. The pumps are worked by a beam *b*. The beam, by its reciprocating motion, causes the plungers $p\,p'$ beneath the pumps to ascend and descend in the barrels of the pumps, forcing at each successive stroke the gas and water together into the condenser. About ten minutes are required to get the charge up, and the bottling then goes on uninterruptedly.

Messrs. Tyler & Son have invented single and

double soda-water machines of ingenious construction. Mr. W. Cox, of Manchester, has patented an apparatus in which the impregnating gas may be sustained at a pressure sufficient to cause its absorption by the water without the aid of force-pumps. Bakewell's apparatus is another contrivance, applicable to the preparation not only of cooling drinks, but of effervescing drinks also, whether tonic, aperient, diuretic, antacid, or pectic. In short, every aerating apparatus may be said to comprise these two parts—one to produce a gas, and one to mix the gas with water.

WAX, an organic product of considerable importance, obtained from different sources, the chief of which is the beehive, where it is used by the bees in the formation of their cells. It has long been a matter of dispute among naturalists, whether the bee collects wax already formed in plants, or secretes it from sugar in the mechanism of its body. The latter view of the case, in accordance with the original observations of Huber, is that which is now generally adopted. It appears that those working bees, to which the manufacture of wax is assigned, take a quantity of honey or sugar into their stomachs, suspend themselves in a festoon, by each insect attaching the claws of its fore-legs to those of the hind pair of the insect above it, and in this way, forming a number of festoons crossing one another in all directions, they appear like a dense curtain. They remain in this position for 24 hours, during which the secretion of wax takes place. The secretion is formed in certain membranous bags in the body of the bee; and, as the secretion goes on, the wax oozes through the membrane, and forms in thin plates on the outside. The process being complete, one of the insects detaches itself from the rest, proceeds to the top of the hive, and begins to build. It grasps one of the plates of wax by means of a pincer, formed at one of the joints of the leg, and draws it forward, when it is conveyed by one of the fore-claws to the mouth. The insect, with its mandibles and proboscis, reduces the plate to a riband of wax, softening it with a frothy kind of liquor, which makes it white and ductile. The other insects proceed in a similar manner, and with such celerity, that in a new hive, a comb 20 inches long by 7 or 8 inches broad, will be constructed in 24 hours, and in five or six days the hive will be half filled.

The wax thus produced is more or less yellow in colour, and has an odour resembling that of honey. The beautiful geometrical form in which it is arranged in the honeycomb is well known. When the wax has served its purpose in the domestic economy of the hive, it is collected for manufacturing purposes, by first allowing the honey to drain off, or to be pressed out, and then boiling the combs in water, with frequent stirring, that the wax may not burn. In this way the combs are completely melted, and the liquid is then poured through hair-bags, which are pressed as long as any wax continues to pass through. The sediment remaining in the bags is also boiled over again, and more wax extracted from it. During the operation, the wax from each bag is received in a vessel of cold water placed beneath it, and answering the double purpose of cooling the wax, and preventing it from sticking. The wax is melted a second and a third time, and passed through bags of increasing fineness on each occasion. Lastly, it is melted once more without water, and poured into pans or moulds wider at the top than at the bottom, and wetted with cold water to prevent sticking. The conical shape of the cake thus produced is advantageous in two ways; it is more easily disengaged from the pan, and it has all its sediment or dross collected into a small space at the under surface, and there is consequently less waste in removing it. The moulds are kept in a warm room until the wax has solidified, otherwise the cakes are apt to crack across the middle. This method, though commonly employed, is tedious, consumes much firing, and wastes a considerable amount of wax; for these successive meltings and removal of dross cannot be effected without loss. Attempts have been made to expedite the process; and those of Mr. Bagster[1] recommend themselves by their simplicity. This gentleman gives directions for obtaining a marketable wax from the combs by a single operation, without either straining or pressing, in the following manner. In an earthen vessel, much narrower at bottom than at top, is placed water and *aqua fortis*, in the proportion of 1 ounce of the latter to every quart of the former. When these are well blended, as many good wax-combs are put in as will reach, when melted, to within a finger's length of the top of the pan. The pan is then set on a clear fire, and stirred while the wax is melting, and until it has boiled long enough to liquefy the whole completely. It is then removed from the fire, and allowed to cool gradually. The wax then forms into a cake at the top, and the impurities are underneath: these arrange themselves in two layers, the lowest of which consists almost entirely of dross, but the next contains a certain amount of wax. When the cake of wax is turned out of the pan, both these drossy layers are removed, leaving the cake pure; but the upper drossy layer is boiled over again with more combs, and with any scrapings which it may have been necessary to make from the upper surface of the wax in order to leave it quite free from extraneous matters. Old combs that have wax in them, or other descriptions of refuse that have been pressed, but yet retain a considerable portion of wax, are pressed down in a close tub or vessel in a house for five weeks. This causes the impurities to ferment and rot, without affecting the wax, which may then be treated as above described, and will yield a fine yellow wax, little inferior to that of the best combs. Where very great purity is required, the best empty virgin combs are put into the same kind of vessel employed in the preceding process, but with only a quarter of a pint of water, to keep the wax from burning. The pan is then set over a clear fire, and stirred until it boils. At this time a clear yellow froth begins to rise

(1) "The Management of Bees." By Samuel Bagster, jun. London, 1834.

up, which froth is to be skimmed off into a pan placed close at hand. The fire must be so managed that this froth shall continue to rise without boiling over, and a succession of skimmings are thus obtained, which form a very pure description of wax. When no more froth will rise, the residue is turned out into a vessel of cold water, and can be boiled up again with other combs. This method is only available with fine combs.

By the above processes, bees-wax is freed from impurities, but is not deprived of its natural yellow colour. For the greater number of uses to which the substance is appropriated, it is, however, necessary that the wax should be rendered perfectly white. This is effected by exposing it in thin ribands on a bleaching ground, where it is subjected to the action of light, air, and moisture, and loses both colour and odour. On a large scale, wax is purified and bleached by first melting it with hot water or steam in a large vessel of tinned copper or wood, letting it settle, and then running off the clear wax while still liquid into a trough perforated at the bottom with a line of holes, through which the wax passes, and falls upon revolving wooden cylinders beneath, which are half immersed in water, and by their action form the wax into thin films or ribands. These films are placed upon long webs of canvas, raised from the ground, and exposed in an open field to the action of the weather; their only covering being a thin netting, which prevents their being blown away by the wind, but does not hinder the free action of the air and sun upon them. They are occasionally watered, if the weather be dry; and if one or two operations do not suffice, the bleaching process is repeated until the effect is gained. Sometimes the colour seems obstinately permanent, and the whole of the wax has to be collected, remelted, and passed over the wet cylinders, so as to obtain new films, with fresh surfaces to be acted upon. The bleaching process is much more quickly accomplished by means of chlorine; but wax thus whitened does not burn well, owing to a portion of chlorine which remains in it combining with a portion of the hydrogen of the wax, and forming muriatic acid, which escapes in vapour into the room. Another method of expediting the work is, to add to 1 pound of melted wax 2 ounces of pulverised nitrate of soda, and then to stir in by degrees 1 ounce of sulphuric acid, diluted with 9 ounces of water, keeping the mixture warm all the while. When all the acid is added, it is allowed partially to cool, and the vessel is then filled up with boiling water and set aside. The cake of wax, when cold, is put into boiling water, in order to remove all traces of sulphate of soda and of acid: it is then white, and should be perfectly free from nitric acid, which, if present, would render it liable to become yellow. Bleached wax contains less carbon and more oxygen than yellow wax. It is translucent in thin slices, insoluble in water, and varies in specific gravity from 0·960 to 0·966. At a temperature of 85°, it admits of being kneaded; and at 150°, it fuses. When heated with boiling alcohol, it is separable into two principal substances of variable proportions, which are *Myricine*, almost insoluble in boiling alcohol, and which appears as a greyish white substance, without any crystalline texture; and *Cerine*, which in its purest form is deposited from the alcoholic liquor, in delicate needle-like crystals. A third substance, called *Ceroleine*, is found to remain in solution in the alcohol when it has become cool. When subjected to dry distillation, the bleached wax evolves margaric acid, and a crystallizable substance, analogous in its composition and physical properties to paraffine. Certain liquid hydrocarbons, olefiant gas, and carbonic acid, are at the same time evolved. The distilled product concretes into a buttery mass, and contains no sebacic acid. On distillation with lime, a quantity of the crystallizable substance just referred to is obtained, together with yellow oils of complex composition.

Chemists are not agreed in their application of the term *wax* to various substances which possess waxy properties; but those named in the following table are often quoted as such. The composition of these substances is said to vary in the same way as that of the fat acids, and they appear to pass into each other by the addition of C_2H^2; as in the following formulæ:—

Bees wax	$C_{34}H_{34}O_2$
Chinese wax } Palm wax }	$C_{36}H_{36}O_2$
Oxidised Chinese wax	$C_{36}H_{36}O_3$
Myrtle wax	$C_{36}H_{36}O_5$
Cerosine	$C_{48}H_{48}O_2$
Cerosinic acid	$C_{48}H_{48}O_3$

In all the varieties of wax (with the exception of that of the cork-tree), the atomic relation of the carbon to the hydrogen is 1:1.

The above substances, as obtained from the vegetable world, are of far less importance than the product of the bee, yet they are deserving of notice. Several species of myrtle (*Myrica*) yield the product called *Myrtle-wax*. This is especially obtained from *Myrica cerifera*, which flourishes in Louisiana, the berries of which are incrusted with wax. By boiling these in water, a quantity of hard brittle wax of a pale green colour is obtained, of the specific gravity 1·015, the fusing point being 110°. A somewhat similar wax is obtained from *Myrica cordifolia*, a shrub which grows at the Cape of Good Hope. The stems and leaves of palm-trees also secrete the substance called *Palm-wax*. Such is the hard brittle greenish yellow wax which we obtain from Rio de Janeiro. It is soluble in boiling alcohol and ether; it fuses at about 160°. A white and crystalline wax, resembling spermaceti, is obtained from a kind of sumach, *Rhus succedaneum*, and is known in commerce as *Chinese* or *Japan wax*. It is soluble in naphtha, but scarcely so in alcohol and in boiling ether. It forms a soluble soap when boiled in a solution of caustic potash. It fuses at about 180°. Another wax, having the same fusing point, is found upon a hard and ligneous variety of the sugar-cane, and is known as *sugar-cane wax* and *cerosine*. This is soluble in boiling alcohol, but sparingly so in boiling ether. By boiling the bark

of the cork-tree, *Quercus suber*, in alcohol, and distilling off the alcohol, a quantity of yellow crystals are obtained which form *cork-tree wax*, which may be purified by repeated solution and crystallization. Nitric acid converts this substance into a peculiar acid, called *cerinic acid.*

The demand for wax is great in Roman Catholic countries, where gigantic candles of this substance are required for the service of the several altars; but the great improvement in the manufacture of composite candles has reduced the demand for wax candles as an article of domestic use. For the manufacture of wax candles and tapers, see CANDLE.

The amount of wax produced in this country is very large, but a considerable quantity is likewise imported from abroad. In 1840, nearly 4,000 *cwts.* were imported from the western coast of Africa, nearly 2,000 *cwts.* from Tripoli, Tunis, &c., and more than 1,000 *cwts.* from the East India Company's territories. This was at a time when the very heavy duty of 10*s.* per *cwt.* was laid upon this article. In 1842, the duty was reduced to 1*s.* and 2*s.* the *cwt.* The adulteration of this substance was great during the existence of the heavy duties, and is still practised to a less extent. The adulterants of yellow wax are earth, pea-meal, resin, &c. Those of white wax are white oxide of lead, white tallow, and potato-starch. Oxide of lead may be detected by simply melting the wax in water, when the oxide falls to the bottom; tallow is discovered by the dull opaque white which it gives to the wax, and starch is detected by means of sulphuric acid, which carbonizes the starch without acting on the wax.

WEAR, a dam, also called a *weir*, formed across a river for maintaining its waters at a level necessary for its navigation. It is also used for directing the water towards a mill, and likewise for taking fish.

WEAVING is the art of combining threads, yarns, filaments, or strips of different materials, so as to form a kind of cloth or textile fabric. This art has its origin in the necessities of man's nature; the rudest nations have practised, and continue to practise it, and the most refined nations have received from the rudest the principles of the art, on which they have engrafted improved details and mechanism.

The fibrous parts of plants, together with rushes, straws, and grasses, woven into a kind of matting, form the simplest kind of weaving, and probably preceded the art of spinning or twisting the material into yarn, and doubling the continuous lengths of yarn into thread, preparatory to weaving. The spinning of fibrous materials into continuous lengths is referred to by the inspired writer as an invention suggested by a higher power than human, at an early period of the world's history. Moses declares (Exod. xxxv. 25), that "all the women that were wisehearted did spin with their hands." We also learn from the same chapter (verse 35), that weaving was practised by those whom the Almighty had "filled with wisdom of heart to work all manner of work of the engraver, and of the cunning workman, and of the embroiderer in blue, in purple, in scarlet, and in fine linen, and of the weaver, even of them that do any work, and of those that devise a cunning work."

The Egyptians became celebrated at an early period of the world's history for their woven fabrics. Although the looms depicted on the tombs at Thebes are rude in construction, the fabrics produced by their means were of a fine and costly character, as, at the present day, the exquisite muslins of the Hindoo workmen are produced by rude and apparently inefficient machines. Specimens of the skill of the ancient Egyptian weaver have been preserved to us in the cloths in which the Egyptians were accustomed to wrap their mummies. Mr. Thomson describes some mummy cloth, examined by him, as being beautiful in texture and peculiar in structure. "It was free from gum, or resin, or impregnation of any kind, and had evidently been originally white. It was close and firm, yet very elastic. The yarn of both warp and woof was remarkably even and well spun. The thread of the warp was double, consisting of two fine threads twisted together: the woof was single. The warp contained 90 threads in an inch; the woof or weft only 44. The fineness of these materials, estimated after the manner of cotton yarn, was about 30 hanks in the pound. The subsequent examination of a great variety of mummy-cloths showed, that the disparity between the warp and woof belonged to the system of manufacture, and that the warp generally had twice or thrice, and not seldom 4 times, the number of threads in an inch that the woof had. Thus, a cloth containing 80 threads of warp in the inch, of a fineness about 24 hanks to the pound, had 40 threads in the woof; another, with 120 threads of warp of 30 hanks, had 40; and a third specimen, only 30 threads in the woof. They have each respectively double, treble, and quadruple the number of threads in the warp that they have in the woof. This structure, so different from modern cloth, which has the proportions so nearly equal, originated probably in the difficulty and tediousness of getting in the woof when the shuttle was thrown by hand, which is the practice in India at the present day, and which there are weavers still living old enough to remember was the universal practice in this country." Mummy-cloths were of linen, the finest of which appeared to have been made of yarn of nearly 100 hanks to the pound, with 140 threads in the inch in the warp, and about 64 in the weft. Striped and dyed goods were also made, indigo being used as one of the dyes. Herodotus speaks of it, as a peculiarity among the Egyptians, that the men wove. Some of the ancient looms were horizontal, others vertical; in the latter case, the weft was driven upwards, with a shuttle about ½ a yard in length.

The productions of the loom, among the ancient Greeks and Romans, would probably rival in beauty and variety the damasks, shawls, and tapestries of modern art, and their patterns frequently represented mythological subjects. The art of weaving formed not only a distinct trade, but it was also a domestic employment, wool being the chief material woven. Minerva was the patron saint of the art, and she was

regarded as the friend of industry, sobriety, and female decorum. The work was chiefly performed by female slaves, under the direction of the mistress of the house, who with her daughters assisted therein, instructed beginners, and finished the ornamental parts. During the early ages, females in Europe were the chief weavers; and as the preparation for the loom, or spinning the yarn, was chiefly performed by girls and young unmarried women, they were called *spinsters*, a term which is still retained. About the 4th century, men began to practise weaving, a circumstance which St. Chrysostom deplores as a mark of the prevailing sloth and effeminacy among men. Some of the more opulent heathen temples kept an establishment of female weavers, for supplying the shawls and furniture used in the religious rites. Young females of the highest rank were sometimes selected for weaving the shawls used in some of the processions. Among the ancients, striped goods were produced by making the warp threads alternately white and black, or of different colours of a different series, according to a prescribed pattern. The Greeks were acquainted with the mode of *mounting the loom*, or arranging a number of strings, so as to separate the warp threads into two or more groups, between which the weft was passed; the leash, *μίτος*, being one such string, and a woven pattern was termed *δίμιτος*, *τρίμιτος*, or *πολύμιτος*, according as it contained two, three, or more groups of strings, or, in the language of modern weaving, *leaves of healds* or *heddles*. Variegated patterns were also produced by using warp threads of one colour, and weft threads of different colours, changed at regular intervals. Checked and striped goods may have been first produced by combining the natural varieties of wool, such as white, black, brown, &c. Most of the other varieties, in appearance and quality, were produced by means of the weft, the warp being more twisted, and therefore stronger and firmer than the weft. The warp and the weft were spun from different kinds of wool, and after the piece had been woven, the fuller carded out the nap. Rich and ornamented materials, introduced into the fabric, were made to form part of the weft, as in the "vestis subserica," where the weft was of silk; in other cases it was of gold, or of wool, dyed with Tyrian purple, or of beaver's fur.[1]

The ancient mode of weaving among oriental nations is illustrated by the loom of the modern Hindoo weaver. It consists of two bamboo rollers, one for the warp, the other for the woven cloth, and a pair of healds for parting the weft. The shuttle is similar to a large knitting needle, and is somewhat longer than the breadth of the cloth; it is also used as a *lay* or *batten* for driving home the weft threads. The weaver erects this rude apparatus under the shade of a tree, forms his seat by digging a hole for his legs, in which are also placed the *treadles;* he stretches his warp by fastening, by means of pins in the turf, two bamboo rollers, at the proper distances apart; he attaches the heddles to a branch of the tree overhead, or to a bamboo rod extended between two trees; and taking his seat at the edge of the hole, he inserts the great-toe of each foot into a loop, which serves for a treadle; and thus, raising the alternate threads of the warp, he draws the weft, and strikes it close up to the web with his long shuttle. The warp is previously dressed, by means of rice-water. The weaver is assisted by a pirn-winder, whose duty it is to supply weft, mend broken threads, &c. The method of warping is to fix sticks in the ground at certain distances, and to lead round them the yarn previously wound upon pieces of split bamboo, attached to a centre stick held in the hand. The yarn is spun by women by means of the distaff.

The art of weaving gradually spread from the East to the West. The time of its introduction into Britain is uncertain. It was practised for several centuries as a domestic employment, and ceased to be such when the factory system with automatic-machines and steam-power were found sufficient in a single mill to perform the work of many thousands of human hands.

Section I.—Varieties of Weaving.

In a piece of woven cloth, two distinct sets of yarns or threads are to be distinguished; these traverse the *web* in different directions, usually at right angles to each other. The threads which form the length of the web are called the warp-threads, or simply the *warp*. The thread which runs across the cloth is called the *weft* or *woof*, and may be regarded as one unbroken thread, passed alternately over and under each thread of the warp, until it arrives at the outside one, when, passing round and under that, it returns back over and under the threads to the outer thread at the other side or edge; passing over those yarns when proceeding in one direction, and passing under them when in the opposite direction, by which means the warp-threads are closely woven together. This constitutes what is called *plain weaving*. Fig. 2302 represents the appearance of a piece of plain

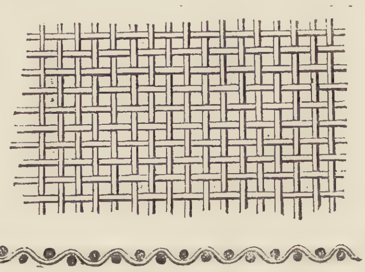


Fig. 2302. PLAIN-WEAVING.

cloth seen through a microscope: the alternate intersections of the threads are shown in the lower figure.

In *twill* or *tweel* (from the French *touaille*), which comprises an extensive variety of woven fabrics, such as *satin*, *bombazeen*, *kerseymere*, the threads of the warp and woof do not cross each other alternately, but only the third, fourth, fifth, sixth, &c., cross each

(1) For further information respecting the art of weaving among the ancients, we must refer to Mr. Yates's "Textrinum Antiquorum;" and also to Professor Smith's "Dictionary of Greek and Roman Antiquities," article *Tela*.

other. Fig. 2303 is an enlarged representation of a piece of tweeled cloth, by which it will be seen, in this specimen, that the same thread of weft is *flushed*

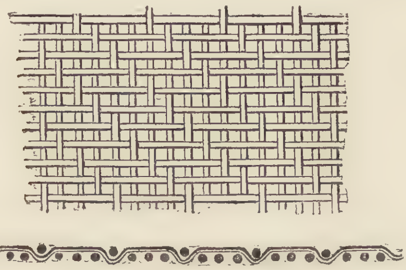


Fig. 2303. TWEELED-WEAVING.

or separated from the warp, while passing over 3 threads, and is held down while passing under the fourth. A cloth of this kind turned on the other side would present the same appearance in the warp, every fourth thread appearing to be interwoven with the weft, and the remaining three threads flushed. In twilled fabrics, the point where the threads of the warp cross each other form diagonal lines, parallel to each other, across the face of the cloth, the degree of obliquity varying with the number of warp threads flushed. In the coarsest or *blanket-twill*, every third thread is crossed. In finer fabrics, the threads intersect each other at intervals of 4, 5, 6, 7, or 8 threads; in some silk stuffs, as in *full satin twill*, there is an interval of 15 threads. In weaving twills, the loom is mounted in a peculiar manner. In plain-weaving, the warp threads are passed through 2 healds, one heald raising every other thread of the warp, in order to admit the shuttle; but in twilled cloth, there is a number of healds equal to the number of threads contained in the interval between two intersections of the warp and weft. Thus, when every third thread is to be interwoven, three leaves are required; if every sixth thread, six leaves, and so on; hence twills are distinguished by the number of leaves required in weaving them, as a *three-leaf twill*, a *four-leaf twill*, and so on. Twills are frequently used by the silk-weaver for the display of colour, and also for the sake of strength, thickness, and durability. In fabrics, where the threads cross each other at distant intervals, there are fewer deviations from the right line, and, consequently, less liability to chafe and to wear. By this method, also, a larger quantity of materials can be collected into the same space than in plain weaving, and this of course gives greater durability.

Pile-weaving. In addition to the usual warp and weft threads, a third thread is introduced in the course of the weaving, and is thrown into loops by being woven over wires of the breadth of the cloth. In the *Brussels-carpet* these wires are simply drawn out, and the loops left standing; but in the *Wilton-*

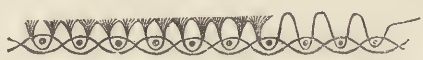


Fig. 2304. STRUCTURE OF VELVET.

carpet they are cut out, by passing a sharp knife along a groove in their upper surface. In this way a nap or pile is formed, as in the various kinds of *velvet, velveteen, fustian*, &c. See Fig. 2304.

Figure-weaving consists in ornamenting the cloth with figures, flowers, and other devices, for which purpose the warp is divided among a number of healds, which can be lowered at pleasure by separate treadles, while threads of different colours may be concealed or brought up to the face, or made to change places, according to a prescribed order. In figure-weaving, the *draw-loom* or the *Jacquard apparatus* is used.

Gauze-weaving. The essential feature of this style of weaving is, that between every two casts of the shuttle, the warp threads, are made to cross each other, so that the weft threads, represented by black

Fig. 2305. GAUZE-WEAVING.

dots in Fig. 2305, are separated from each other, and a light transparent texture produced.

Lace-weaving. In this variety the threads of the weft are twisted round those of the warp, as in Fig. 2306. The term *net* is applied to a large number of light cross-woven goods, and, according to the mode in which the threads cross each other, we get *whip-net, mail-net, pattern-net, drop-net, spider-net, balloon-net, Paris-net*, &c. These varieties of net were for-

Fig. 2306. LACE-WEAVING.

merly produced at the loom with warp threads stretched horizontally, and weft threads thrown in by a shuttle. *Bobbin-net* is produced by a self-acting machine of peculiar structure.

Knitting, or *stocking-weaving.* Knitting is a kind of weaving adapted to the production of small articles, and it differs from the foregoing varieties, in the circumstance that only one thread is employed for warp and weft. The thread is passed in each stitch, first in that of the weft, then in that of the warp, so as to form successive rows of loops, the loops of each row being drawn through those of a former row. In stocking-knitting, the whole fabric consists of one continuous thread.

Darning is a kind of weaving on a small scale, performed with one thread, with the assistance of the needle; it is used for filling up a hole in a woven fabric.

Netting. In netting, the threads or cords are tied into hard knots at their points of intersection, so as to form *meshes*, which always continue of the same size.

Section II.—On Plain Weaving.

In a piece of plain cloth, as already noticed, the threads which proceed in the direction of the length are called the warp; also the *twist*, the *caine* (from the French *la chaine*, or the chain), and also *organzine.* The threads which run in the direction of the width of the cloth are called the *weft;* also the *woof*, the *shoot*, and the *tram.* Plain weaving, where the

weft threads pass alternately over and under those of the warp, is performed at a *loom*, of which the essential parts are — 1st, an arrangement for stretching the warp; 2d, a contrivance for raising every alternate thread, or half the threads of the warp, and depressing the other half, so as to open a space or *shed* for the shuttle which carries the weft; 3d, a contrivance for striking each weft thread close up to the one previously thrown.

The frame of the loom consists of four upright posts, connected by cross beams at the top and bottom. At one end is the *beam* or *yarn roll*, B, Fig. 2307, on which the warp threads are wound, and at the other end, is the *cloth-beam*, C, on which the cloth is wound as it is finished. In turning round the beam C, fresh portions of the warp are wound off from B; and in order to keep the yarn threads ex-

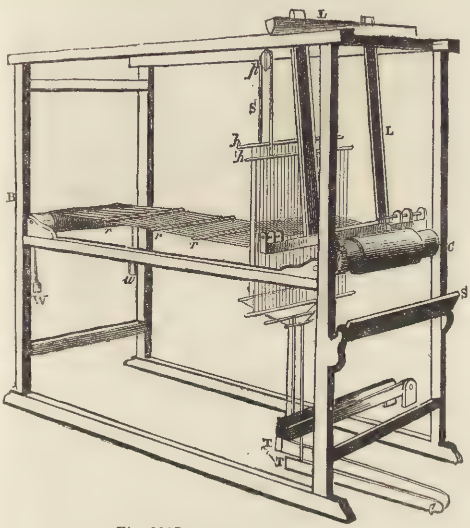


Fig. 2307. THE COMMON LOOM.

tended, weights W *w* are hung by cords to the warp-beam, or a large stone may be slung over it. The extended threads of the warp are prevented from becoming entangled by flat rods, *r r*, placed between the alternate threads. The *healds* or *heddles, h, h'*, by which the threads of the warp are alternately raised or depressed, consist of a number of twines, with loops in the middle, through which the warp threads are drawn. The two healds are united by a cord S, passing over a pulley *p*, (collectively called the *harness*,) so that by lowering one heald, the other rises. The warp threads are also passed through the *dents* or teeth of a *reed*, set in a movable swing-frame L, called the *lathe, lay*, or *batten;* shown separately in Fig. 2308, the last term referring to its action in batting or beating home the

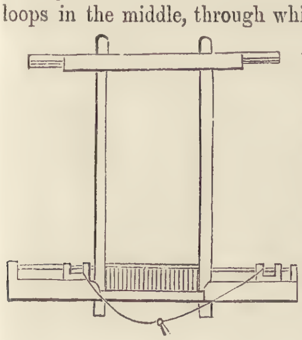


Fig. 2308.

weft to the web. The bottom of this frame is furnished with a sort of shelf, called the *shuttle-race*, along which is thrown the *shuttle*, (two forms of which are shown in Figs. 2309, 2310. The shuttle is a small boat-shaped piece of wood, sometimes moving on wheels, and hollowed in the middle for contain-

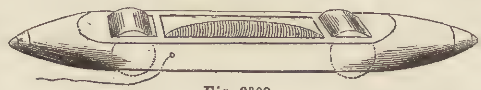


Fig. 2309.

Fig. 2310.

Fig. 2311.

ing the cop of yarn which forms the weft. A small hole at the side of the shuttle allows the weft yarn to run out with the motion of the shuttle. The shuttle may be thrown by hand, or by means of the *fly*. By the latter method the two ends of the shuttle-race are closed, so as to form a trough, shown separately in Fig. 2311, in which two pieces of wood, called *pickers* or *peckers*, are made to move along wires, as shown in Fig. 2308. A string from each picker is attached to a handle, as shown in the same figure, which the weaver holds in his right-hand; and it is thus easy for him, by means of a smart jerk, to project the shuttle along the shuttle-race from right to left, or from left to right. The weaver occupies the seat S, Fig. 2307, and pressing with one foot on one of the treadles T, he lowers one of the healds, the effect of which is to lower all the alternate threads of the warp passing through the loops; the other heald will of course be simultaneously raised, thus forming a shed for the passage of the shuttle. The shuttle is now thrown across the opening thus formed, by which means a thread of weft is stretched across the web, and this is driven close up to the web, by means of the batten, which the driver guides with his left hand. The weaver raises his foot from the treadle T', and presses down with the other foot the treadle T,—the effect of which is to depress the alternate threads which before were raised, and to raise those which were before depressed. The shuttle is again thrown, whereby another thread of weft is drawn across the web; this is driven home by means of the batten; the treadle T is again depressed, and thus the work proceeds with great rapidity. When a few inches of cloth are woven, they are wound on the cloth-beam C by turning a handle at the side, a ratchet-wheel preventing the beam from slipping; but as the weaver must always have a certain length of woven cloth before him, not wound upon the cloth-beam, this would tend to contract in breadth by the contraction of the warp, were it not prevented by

Fig. 2312.

some contrivance. For this purpose, two pieces of hard wood called *temples*, Fig. 2312, are used. Their ends are furnished with sharp points, which pierce the edge or selvage of the cloth on each side, and thus

keep it distended by adjusting the two pieces of wood as shown in the figure.

Plain weaving is not a difficult operation. The treadles must not be depressed too suddenly, or some of the warp threads will be broken, and much time be lost in mending them, before the weaving can be proceeded with. The shuttle must not be thrown with too much force, or it will recoil, and, by slackening the weft thread, injure the appearance of the web. The batten must also be brought forward against the shoot with an equal degree of force at every blow, or the cloth will not be uniform in thickness; and this force must vary with different fabrics and degrees of fineness. The loom should be mounted so that the range or swing of the batten may be proportioned to the texture of the goods. The greater the arc of the circle in which the batten swings, the greater the degree of force with which the shoot is driven home. Hence, the woven cloth should be frequently taken up on the cloth-roll, or the uniformity of its texture may be interrupted by the diminished range of the batten. For coarse or thick goods, the batten should be hung so as to have greater play, and consequently more force, than for fine and light fabrics.

The various processes of weaving are always more intelligible when the construction and action of the common loom are well understood. Hence we have introduced the description thereof thus early. Before, however, the weaver can be set to work, a number of complicated processes are necessary for the preparation of the yarn or thread, and for the mounting of his loom. These processes we now proceed to describe under their respective heads.

Warping.—The yarns or threads used in weaving, although of the same material, differ in *hardness*, or amount of twist, according as they are destined for the warp or for the weft; the harder and more twisted yarns being used for the warp, and the softer or less twisted for the weft. The yarn or thread is supplied by the spinning or doubling-mills in hanks, skeins, or cops. [See COTTON.] The warp threads are wound on bobbins, from which the warp is formed by a process termed *warping*, the object of which is to place the threads alongside of each other in one plane. In some woven fabrics, upwards of 8,000 threads have thus to be placed side by side without entanglement or confusion. The old method, still practised in India and China, was to draw out the warp to its full length in an open field. One of the earliest of our factory contrivances is the warping-frame, consisting of two upright sides, containing a number of wooden or iron pins, between which the yarns are extended. The bobbins of yarns are contained in a frame, and the warper, tying all the ends of the yarns together, attaches them to one of the pins; then gathering all the threads into her hands in one clue, and allowing them to slip through her fingers, she walks to the other end of the frame, and passes the yarns over and round one of the pins, repeating this operation backwards and forwards until enough yarn has been collected to form the warp.

The usual method of laying out the warp, is by means of the *warping-mill*, Fig. 2313, which consists of a large wooden skeleton-reel or frame, with 12 or more sides of determinate length, which serve as a measure for the total length of the warp. The frame is mounted on a vertical axis, and is moved round by means of an endless band, which connects the bottom of the axis with a wheel under the control of the warper. One-sixth of the whole number of bobbins of yarn required to form the warp is mounted in a frame called a *travers*, the bobbins being set loosely upon iron skewers so as to revolve and give off the yarn freely. The yarns or threads are passed through

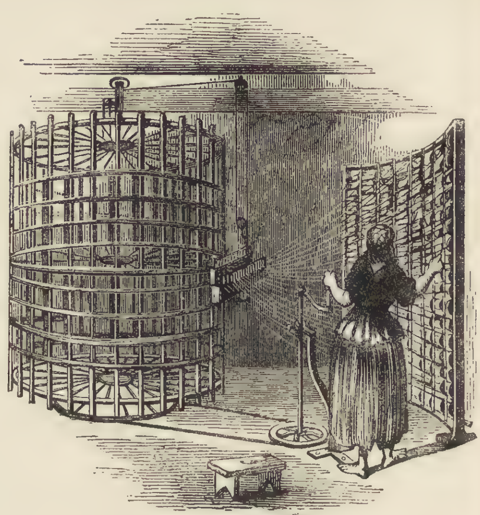


Fig. 2313. WARPING-MILL.

an instrument called a *jack*, or *heck-box*, placed between the bobbins and the frame, and made to slide up and down between two upright posts; it is suspended by a cord, which passes over a pulley, and is secured to the top of the axle, so that as the reel revolves a portion of cord is wound on the axis, and thus the heck is slowly raised from the bottom to the top; when the mill is turned in the reverse direction, the heck descends by its own weight. The heck divides the warp threads into the *leas*, or two alternate sets, one set for each heald; for which purpose the heck-block contains 20 or more steel pins, with an eye in the upper end of each, through which a warp thread is passed. The pins are mounted alternately, so that either may be raised as required. See Fig. 2314. When the threads are passed through the eyes of the heck, their extremities are knotted together, and fixed to a pin on the

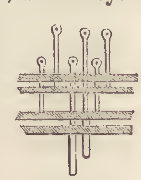


Fig. 2314.

warping-mill. The mill is then turned slowly round, until the top of these pins comes nearly opposite the heck. The warper then lifts half of the heck-frame, and, passing the forefinger of the left hand through one space formed between the threads, and his thumb through the other space, places the yarn upon 2 pins of the warping-mill; the first pin passing through the interval kept by the finger, and

the second through that made by the thumb, by which means every alternate thread is crossed, and the lea is formed. The warp is made to describe a spiral line over the frame, and at the bottom the threads are once more passed over pins. The mill is then made to revolve in a contrary direction, and the warp is made to describe another spiral line from the bottom to the top. The operation is repeated from the top to the bottom, and so on until a sufficient length of yarn is obtained. The leas, or crossing of the threads, is now preserved by tying a band through them at the top and bottom; the warp is then removed from the mill by taking it from the lower pins, and winding it upon a stick, or upon the left hand of the warper, into a large ball. A cotton warp may vary from 400 to 600 yards in length. Care must be taken in warping to avoid broken threads, or to mend them as soon as they are broken.

Beaming.—The next operation is to spread out the warp of yarns upon the yarn-beam of the loom. For this purpose the iron pivots of the beam rest in a frame, and the beam itself is made to revolve, by being connected with a revolving shaft. In order to distribute the warp-threads uniformly over the beam, in the order in which they were laid by the warper, they are passed through a *separator*, or *ravel*, which the weaver holds in his hand, consisting of pieces of cane fixed to a rail of wood, so as to form a rude kind of comb. The teeth of this ravel spread out the warp on the beam to the required length.

Dressing and Sizing.—As the warp threads in the process of weaving are subjected to much tension and friction, they require to be strengthened by a dressing of glue, size, or paste. Cotton and linen yarns are dressed with flour-paste, to which a little brine is sometimes added, to prevent it drying too quickly, and making the yarn brittle. The rollers containing the cotton-yarn are mounted on a frame; the threads are passed through a reed to keep them separate, and then between 2 rollers covered with felt, one of which dips into a trough of paste. The lower roller applies the dressing to the yarn, and the other one squeezes out the superfluous portion. The paste is worked into the fibres by means of cylindrical brushes over and under the warp, moving in a contrary direction to that of the yarns. The dressed warp is dried by being passed over a steam-chest, near which is a revolving fan for keeping up a current, and preventing the air from becoming saturated with moisture. The warp is then passed to the main beam of the loom, over which it is regularly distributed by means of a reed.

The *Sizing Machine*, Fig. 2315, is also used for dressing yarns. It consists of an iron trough, furnished with the steam-jacket, and containing a number of copper rollers arranged as in the figure, over the surface of which the warp is made to travel. The rollers revolve by the friction of the warp, which is thus pressed flat upon them and remains free in the spaces between them, by which means the fibres become impregnated with fluid paste, with which the trough is nearly filled. Two rods stretch along the trough along either side of the warp, in order to keep it in the centre of the rollers. The warp passes out of the trough between two large wooden rollers, which press out the superfluous paste. The warp is then dried by being passed over hot cylinders, or through the air of a hot room. Glue is commonly used in the sizing of woollen warps, for which purpose the warp is passed through a trough containing a gelatinous solution. One end of the warp is passed through a trumpet-shaped hole, at one end of the trough, then under a roller at the bottom, along the trough to another roller, and then through another trumpet-shaped opening at the other end of the trough. It is pulled backwards and forwards through and under these rollers, because it is found that yarns and stuffs require to be alternately immersed in a fluid and squeezed out in order to expel the air entangled in the fibres; otherwise they are not properly penetrated by the fluid. When the woollen yarn is dry, a little tallow is smeared over it.

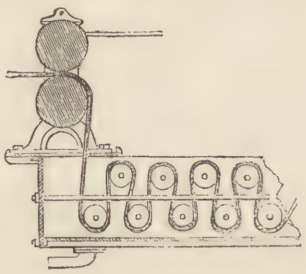


Fig. 2315.

Worsted warps are *scoured* in soap-suds, in order to get rid of the oil used in the process of combing the long wool. On leaving the tub of soap-suds, they are passed between pressing rollers; then *linked* or plaited in a peculiar manner, to prevent the entanglement of the warp threads, and also for the sake of compactness. When wanted for use, each bundle can be readily undone by pulling out one of the ends.

Drawing-in.—When the warp has been regularly wound on the warp beam, every yarn requires to be drawn through the corresponding eye or loop of the healds. This is called drawing-in. For this purpose the yarn-beam is suspended by its ends, so as to allow the warp to hang down in perpendicular threads; the healds are also hung up near the warp ends. The weaver, seated in front of the healds, with an assistant on the other side, picks up every thread in order, and delivers it so that the person on the opposite side may draw it through by means of a small hook. The order in which the threads are to be taken is indicated by the leas-rods, every thread crossing the one next to it. When the warp has been passed through the eyes of the heald, it is drawn through the reed, two threads being passed through each reed-split. The leas-rods being in their proper places, the first thread passes over the first rod, and under the second; the second thread under the first, and over the second, and so on alternately; by which contrivance each thread is kept distinct, and, should it break in the loom, its place can easily be found. A third rod divides the warp into *splitfulls*, two threads passing alternately over and under it. As the work proceeds,

small portions of the warp are knotted together; and the drawing-in being finished, the yarn threads are knotted to strings attached to the warp-beam ready for stretching in the loom. The dents of the reed must be very regular and even, or the warp threads are likely to break, and the texture of the woven fabric liable to irregularity. The number of dents in a reed of a given length, or, as the weaver terms it the *number* or *set of the reed*, determines the fineness of the cloth, two threads passing through each dent. The set of the reed varies in different places. Thus, a 60-*reed* cloth at Blackburn does not indicate the same degree of fineness as a 60-*reed* cloth at Stockport; but the method of computation at Stockport is the more simple, the fineness being estimated according to the number of warp threads in an inch. A Stockport 60-*reed* cloth contains 60 warp threads in an inch; a Blackburn, a Bolton, and a Scotch 40-*reed* all vary in fineness with the set of the reed.

When the cloth is woven, it undergoes a variety of finishing processes, varying with its material, an account of which will be found under BLEACHING — CALENDERING — CALICO-PRINTING — DYEING — WOOL, &c.

SECTION III.—ON PATTERN OR FIGURE-WEAVING.

Uniformity of texture is produced by the warp and the weft threads being of equal fineness, while the texture itself depends on the fineness of the yarn and the set of the reed. Yarns of different degrees of fineness, introduced at intervals into the web, will give two distinct textures, producing a sort of striped pattern, which admits of much variety. When the warp threads are of one colour, and the weft of another, a *shot* pattern is produced, the loom being arranged as in plain weaving. In *striped* patterns, the stripes may be arranged by the warper, who introduces at regular intervals the coloured threads required to make the stripe. Variety is also produced by employing yarns of the same colour, but of different degrees of fineness; or by drawing a larger number of warp threads through some of the eyes of the heald than others. Thus, two or more threads may be passed through the same eye of the heald, or three or more healdfulls through the same intervals of the reed; or, with fixed stripes both methods may be employed. When stripes extend across the cloth, they are thrown with the weft, the weaver employing shuttles containing coloured threads, which are used at proper intervals.

Checks are formed by combining the two methods of striping. The warper first produces an alternation of colours in the warp, by inserting coloured threads at certain times; and the weaver produces a further alternation by throwing in wefts of different colours from one or more shuttles. Stripes and checks are largely manufactured in worsted, in silk, in cotton, and other materials. When the pattern of checks is different at the borders from that at the middle or bosom of the web, they are called shawls and handkerchiefs. *Twills*, or *tweels*, have been noticed in Section I.

Figure-weaving requires considerable preparation in mounting the loom, and differs from plain-weaving in the number and arrangement of the healds, and the method of moving them. As the number of healds is generally too great to be moved by the feet of the weaver, an apparatus called the *drawloom* was in general use until the introduction of the Jacquard machine, and still continues in use in certain localities. In the drawloom, the warp threads are passed through loops formed in strings, arranged in a vertical plane, one string to every warp thread; and these strings were so arranged in separate groups, that when an attendant, called the *drawboy*, pulled the handle which united one group, he drew up all those warp threads which, in the order of the pattern, required to be raised for the passage of the shuttle. The order in which the threads are grouped is determined by a pattern paper or design; it is divided by lines into small squares, so as to represent a woven fabric, and upon it the pattern is drawn and coloured. It thus guides the weaver in building the "monture," or arranging and grouping the various threads; and the order in which the handles are to be pulled or drawn is also arranged so that the weaver and his drawboy may work with ease and certainty. Care, however, is required not to pull the wrong handle, a mistake likely to occur in so monotonous an employment. Such an accident would, of course, throw out the whole pattern. Hence, a mechanical drawboy has been contrived, consisting of a half wheel, with a rim grooved so as to catch into the strings requiring to be pulled down. This half wheel travels along a tooth-bar, with an oscillating motion from right to left, and draws down the particular cords required for the pattern. The building of the monture was often a work of some months, and then only served for one pattern.

Jacquard, the inventor of the apparatus which has caused his name to be so well known, was a straw-hat manufacturer at Lyons. His attention was first directed to the subject of mechanical invention by seeing in a newspaper an offer of a reward for a machine for making nets. He produced the machine, but did not claim the reward. The circumstance becoming known to some persons in authority in Paris, Jacquard was sent for, introduced to Napoleon, and was employed in correcting the defects of a loom belonging to the state, on which large sums of money had been expended. Jacquard stated that he could produce the effects intended to be produced by this loom by far simpler means. He was requested to do so; and, improving on a model of Vaucanson, he produced the apparatus which bears his name. He returned to Lyons with a pension of 1,000 crowns; but his invention was regarded with so much mistrust and jealousy by the weavers, that they attempted to suppress it by violent means. The "Conseil de Prud'hommes," who are appointed to watch over the interests of the Lyonese trade, ordered his machine to be broken up in the public *place*, and, to use the pathetic expression of Jacquard himself, "the iron sold for iron, the wood for wood, and he, its inventor, was

delivered over to universal ignominy." Other countries, however, appreciated the invention, and had it in successful operation, rivalling and even surpassing the products of the French loom, before the Lyonese weavers recognised their folly. The Jacquard apparatus soon got into general use, in the silk, worsted, and muslin manufacturing districts of France and England. The *Jacquard apparatus*, or *loom*, as it is sometimes called, is not really a loom, but only an appendage to one: it is attached to its upper part in a line with the healds, and its function is to raise the warp threads in the order and number required for the pattern for the passage of the shuttle. It has been already stated, that in figure weaving, all the warp threads which rise simultaneously have their appropriate healds. In the drawloom, these were raised by means of cords which connected them into a system, which could be raised as required by the pattern. In Jacquard's apparatus, the warp threads are raised by a number of wires arranged in rows and formed into hooks *h h* at the upper extremities, as in Fig. 2316. These hooks are supported by bars,

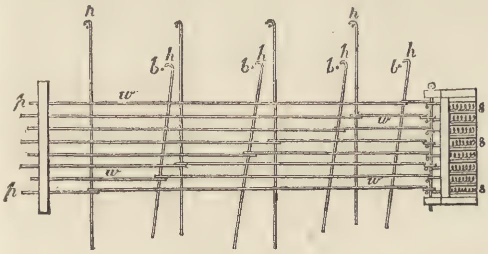


Fig. 2316.

b b the ends of which are represented by dots; and the bars are supported by a frame, which is alternately raised and lowered by a lever attached to and acting with the treadle. If all the bars are raised at the same time, all the warp threads will be elevated; but if some of the hooks be pushed off some of the bars while the others are allowed to remain on, such warp threads only will be raised as are connected with the engaged hooks. Accordingly, there is a contrivance for disengaging the hooks from the bars, and this is effected by means of horizontal wires, *w w*, furnished with loops in the centre, (shown separately in Fig. 2317),

Fig. 2317.

through which the lifting wires are made to pass. These horizontal wires are kept in position by spiral springs *s s* contained in a frame, and the points of the wires *p p* protrude from the opposite side.

Now, it is evident, from an inspection of Fig. 2316, that if the points of the wires be pressed by any force, the wires will be driven into the frame, the hooked wires passing through them will be disengaged from the bars, and the warp-threads of the disengaged wires will not be elevated. When the pressing force is removed, the elasticity of the springs will drive the needles forward, and restore the hooks to the bars The method of driving back the wires is by means of a revolving bar of wood, Fig. 2318, of 4 or more sides, each side being pierced with holes, correspond-

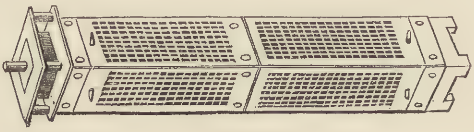


Fig. 2318.

ing in number and position with the points of the needles. One of the sides of this bar is brought up against the points of the wires every time either treadle is depressed. If the side of this bar alone were to be opposed to the points of the needle, the points would simply enter the holes, and no effect be produced: but if some of the holes be stopped while others be left open, the wires which touch the stopped holes would evidently be driven back, and the hooks of the vertical wires attached to them be disengaged from the bars; while those which enter the holes would remain undisturbed, and only the warp-threads attached to their vertical wires would be raised. This stoppage of some of the holes in each face of the revolving bar is effected by covering it with a card containing holes corresponding with those in the bar, but fewer in number; so that, when the points of the wires come in contact with an unperforated part of the card, they are driven back, but when the points enter the holes of the card, the wires are not moved, and, consequently, the hooks of the vertical wires remain on their bars. By this contrivance the intended pattern is made out. The revolving bar presents a new card to the points of the horizontal wires at every quarter revolution, if the bar be 4-sided. The holes in the cards being so arranged as to raise, in succession, those healds which will make out the intended pattern, it is necessary that there should be as many cards as there are threads of weft. Where the pattern is complicated, the number of cards is very considerable. In some of those absurd attempts to represent in one material forms and objects which are easily and naturally delineated in another material, such as the portrait of a man woven at the loom instead of being painted at the easel, the number of cards required is very considerable; for example, the modern Lyonese weavers, to atone for the ingratitude of their ancestors to their illustrious countryman, resolved to erect a monument to his memory; and the result was, one of those extraordinary, but very unnecessary specimens of perverted ingenuity, a portrait of Jacquard, woven in silk, representing him in his workshop, surrounded by his implements, and planning the construction of the Jacquard apparatus. For this "Hommage," as it was called, there were 1,000 threads in each square inch, in both warp and weft; 24,000 cards were required for the pattern, each card being large enough to receive 1,050 holes. In the Jacquard apparatus the cards are fastened together by threads, so as to form a kind of endless chain, one complete revolution of which makes out the pattern, and by continually working this, the pattern may be repeated several times in one warp.

The preparation of the cards for the pattern is a special employment, not undertaken by the weaver. The pattern, on an enlarged scale, is first drawn upon squared paper, as already noticed, and is then repeated in a frame containing a number of vertical threads, corresponding with the warp of the fabric; the workman then, with a very long needle, takes up such threads as are intersected by the pattern, inserting a cross thread under them, and carrying it over all the remaining threads in the same line, repeating the process until he has inserted a sufficient number of threads to make out the pattern. This being done, the threads thus interlaced are attached to a card-punching machine, which resembles in principle the Jacquard apparatus, and is provided with lifting cords, wires, and needles, connected, as in Fig. 2316, so that, by pulling the lifting-cords, the wires or needles

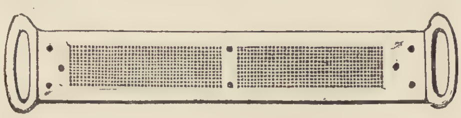


Fig. 2319.

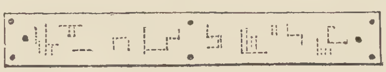


Fig. 2320.

will be protruded. In front of these needles, corresponding with the revolving bar, Fig. 2318, is a thick perforated iron or steel plate, each of the perforations containing a movable steel punch, fitting easily into the hole; the protrusion of any of the needles drives forward the punches which correspond with them, and deposits them in a second similarly perforated iron plate, fitting close to the face of the first. In order that the steel punches may be properly protruded, one end of each warp-thread is connected in succession with the separate lifting-cords of the machine; each thread of the weft is then taken by the two ends and drawn upwards, by which means all the warp-threads passed under by this weft-thread will be raised, and can be collected together in the hand, by pulling them; the lifting-cords to which they are attached will cause the needles to protrude, and these will drive out the cylindrical cutters from the perforations on the fixed plate into the corresponding cavities of the movable plate. A blank card slip is placed upon the latter, which is then removed to a fly-press, and the punches are driven through the card slip. The process is repeated on all the other card slips required for the pattern, the various cards being numbered and attached together in order. The movable plate and the perforated card are represented in Figs. 2319, 2320. The two outer large black spots at each end of the plate are guide-holes corresponding with those in the cards, and are used for tying the various cards together. The other large spots, one at each end of the card, fit into the conical projections of the revolving bar, Fig. 2318. The set of cards required for the production of a pattern is made up into a bundle, with a numbered label, and a portion of the fabric attached to it. In using the chain of cards at the loom, they are arranged in several folds, and are partly supported on a curved board. The Jacquard apparatus has done much to extend the use of figured fabrics, and is applied to various descriptions of weaving. By its means the most beautiful productions of the loom require not more than ordinary skill on the part of the weaver, while the labour of the weaving does not greatly exceed that required for plain goods.

In the foregoing description we have been anxious to convey a clear idea of the principle of the Jacquard apparatus. The applications of this principle lead to a great variety of apparatus which it is impossible to describe in this place. We may, however, notice one or two varieties of Jacquard apparatus in the Great Exhibition. :—" In Mr. Barlow's double Jacquard loom two cylinders are employed, and the cards are disposed upon these in alternate order, so that while one cylinder with its cards is brought into action upon the horizontal wires, the other is withdrawn for the purpose of rotating it and shifting the card, and *vice versâ*. By this arrangement the loom can be worked with a velocity 40 per cent. greater than that of the ordinary construction. The steadiness of its action is greatly increased, and the strain upon the warp diminished by another improvement, which consists in lowering the warp-threads as well as raising them; whereas in the ordinary Jacquard loom those threads which are not carried up by the lifting bars, are allowed to remain in the horizontal position."[1] Messrs. Taylor and Son exhibited a power-loom with four Jacquard cylinders working simultaneously. M. Moreau exhibited a Jacquard loom in which a cylinder like that of a barrel-organ, provided with pegs capable of being shifted to suit any required pattern, is substituted for the usual chain of cards.

The wear and tear to which the cards are subjected in the ordinary Jacquard loom is such, that in the weaving of carpets they often require to be made of iron plate. In Martin's new Jacquard loom, lately described by Mr. E. Laforest at the Institution of Civil Engineers, the object has been to substitute for the heavy cards a sheet of prepared paper punched with given apertures like the cards of the old machines, but instead of being a series of pieces 2½ inches wide, laced together, the punched paper formed a continuous band only ⅝ of an inch wide, thus so diminishing the bulk that the weight of the new band, as compared with that of the old cards, was in the proportion of 1 to 11. The method by which this desirable result had been attained was explained to be chiefly an arrangement which permitted the 400 spiral springs on the needles used in the old machine to be dispensed with, when, as a consequence, the force and wear and tear due to their resistance would be done away with, and fine and light wires could be made to do the work of strong and heavy ones. The next point brought forward was, that, like the bulk and weight, the cost of the cards under the new

(1) Jury Report. Class VI.

system would be greatly reduced. It was shown that, by an improved system of punching machinery, the bands could be cut from a design, previously perforated, at the rate of 3,000 cards per hour, and any duplicate could be produced with equal celerity; it was also stated, that by these means, when a pattern became fashionable any number of looms might be set to work on it, in about as many days as it had previously required weeks, under the old system. The price of the old cards was 6*s.* 9*d.* to 8*s.* 6*d.* and upwards per 100 for new sets, and 5*s.* 6*d.* for recuts: whereas the new paper bands would cost 1*s.* per 100, and 6*d.* per 100 for recuts. The comparison of cost of 3,000 cards (an average band) would therefore stand thus:—

	Cost.	Weight.	Length.
3,000 cards at ...... 6*s.* 9*d.* per 100	10*l.* 2*s.* 6*d.*	90 lbs.	600 ft.
3,000 new bands at 1*s.* 0*d.* per 100	1*l.* 10*s.* 0*d.*	8¾ lbs.	63 ft. 9 in.

In reference to durability, it was stated that a band had been in constant work for two years, although used on a heavy waistcoat piece.

Section IV.—On Mechanical or Power Weaving.

It was long a mechanical problem to construct a machine which should repeat with precision the somewhat complicated motions required in weaving. These, as we have seen, consist in,—1st, alternately depressing the treadles; 2d, throwing the shuttle between the alternate threads from right to left, and from left to right; and, 3d, driving home the weft by means of the batten. Towards the end of the seventeenth century, M. de Gennes forwarded the drawing of a loom for mechanical weaving to the Royal Society of London. It does not, however, appear that this machine was more successful than many other similar contrivances which were attempted during the eighteenth century. In 1784, however, Dr. Cartwright had his attention directed to the subject of Arkwright's spinning machinery, the productiveness of which was such, that on the expiration of Arkwright's patents it was remarked, that "weaving mills" would be required to work up the yarn. After some time, Dr. Cartwright succeeded in constructing a weaving machine, and by its means weaving a piece of sailcloth. The machinery was rude, and, to use the words of the inventor, "the warp was placed perpendicularly, the reed fell with the force of at least half a hundredweight, and the springs which threw the shuttle were strong enough to have thrown a Congreve rocket. In short, it required the strength of two powerful men to work the machine at a slow rate, and only for a short time. Conceiving, in my great simplicity, that I had accomplished all that was required, I then secured what I thought a most valuable property by a patent, April 4th, 1785. This being done, I then condescended to see how other people wove; and you will guess my astonishment, when I compared their easy modes of operation with mine. Availing myself, then, of what I saw, I made a loom in its general principles nearly as they are now made; but it was not till the year 1787 that I completed my invention, when I took out my last weaving patent, August 1 of that year." Dr. Cartwright established a power weaving-mill at Doncaster; but his loom was found to require, from time to time, so many modifications, that after expending between 30,000 and 40,000*l.* he was compelled to abandon his undertaking.

In the year 1791, a mill was erected by other parties at Manchester, adapted to 400 of his improved power-looms, for which he was to receive a certain royalty for the use of his patent right. The operative weavers opposed the undertaking on the ground that it would deprive them of work; they even set fire to the mill which contained the power-looms, and threatened to oppose by force their introduction elsewhere; but, as ignorance is not capable of arresting the progress of improvement in a free country, the power-loom outlived the malice of the Manchester operative weavers. In 1798, it was applied at Glasgow to the weaving of cotton fabrics, since which time it has undergone various improvements, and may now take its place with the beautiful automatic machinery which has been described under Cotton. The country was not insensible of the merits of Cartwright's invention, and of the losses which he had sustained in bringing it to bear, for in the year 1808 the House of Commons voted him the sum of 10,000*l.*

Fig. 2321, represents the essential parts of the power-loom independently of its framing, and the

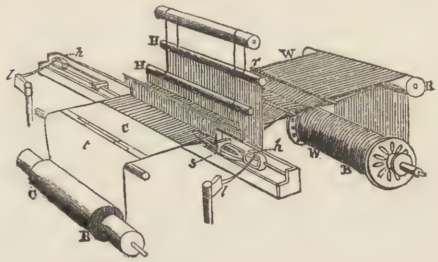


Fig. 2321. WORKING PARTS OF POWER LOOM.

parts for communicating motion. The warp W, wound upon the warp-beam W B, passes over a roller R, and is then carried through two healds H H',—which form the shed for the passage of the shuttle; this is driven along the shuttle race by a kind of hammer *h* worked by a lever *l* moving through a small arc of a circle. The finished cloth C is kept distended by the temples *t*, the portion wound upon the cloth-beam being shown at C, B. Fig. 2322, is an enlarged representation of the apparatus for projecting the shuttle through the shed.

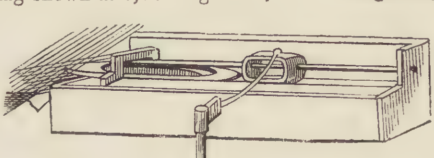


Fig. 2322.

In the power-loom, there are five distinct actions performed by steam-power:—1st. To raise and depress the alternate threads of the warp. 2d. To throw the shuttle. 3d. To drive up each thread of weft with the batten. 4th. To unwind the warp from the warp-beam. 5th. To wind the woven fabric on the cloth-roller. There is also a 6th action frequently introduced, viz. an arrangement for stopping the loom in case a thread should break, or when the shuttle *traps*, that is, sticks in its course through the thread, or when the cop of yarn contained in the shuttle is run out. The mode of producing this automatic stoppage varies according to the general arrangement of the loom; but the following brief description of one variety will illustrate the principle. When a weft-thread breaks, there is no delivery from the shuttle; there is a consequent want of filling to the cloth; and the reed, in beating up, will not meet with that resistance which it did when the filling of the weft-thread was perfect. In the beating up of the lay, therefore, the reed frame will be driven back a little less than usual; it will act less upon a particular lever; the lever will act less upon a rod; the rod will fail to move a click over a tooth of a ratchet-wheel; and the yarn-beam will cease to give out warp.

The following arrangement is now more common:—attached to the back of the beam which carries the shuttle is a three-pronged piece of iron, somewhat like a large fork, over which the weft passes. A two-pronged piece, hinged to the beam, falls on the thread stretched across the fixed prongs, and is prevented by the thread (if this be perfect) from falling lower so as to set free a catch. The prongs of the hinged piece always tend to fall through the fixed prongs at each blow of the beam, and do so fall through if the thread is not stretched across the fixed prongs to prevent the passage of the movable piece. If they do fall through, a catch is released, which allows a tumbling bob to fall, and this shifts the strap from the fast to the loose pulley. The projecting arm of the hinged piece serves to lift the prongs at each movement of the beam, to allow the shuttle in its passage to lay the weft across the prongs.

A self-acting contrivance of this kind for stopping the bobbin in the doubling-frame on the breaking of a thread is shown under SILK, Fig. 1984. Dickinson & Willan's Power-loom embodies a modification of the stop-motion, by which the common slip-rod and frog are dispensed with, doing away with the concussion arising from their coming in contact by stopping.

Power-looms are usually contained in one large room or *shed* on the ground floor. When 1,000 or 1,500 of these looms are at work at the same time, they produce a noise which overpowers other sounds. The looms are attended by women and girls, who see that the work goes on properly, supply the spindle of the shuttle with fresh cops when required, and adjust the temples from time to time. One woman and a girl can attend to four looms; or one woman, unassisted, can attend to two. There is also an overseer, who has the care of 70 looms, whose duty it is to correct defects in the machinery, and to remedy any mishaps which are beyond the power of the women. The length of calico woven at each loom is variable; in some cases 600 yards of warp are formed into 10 divisions; in other cases the divisions are from 25 to 70 yards each. When the piece of cloth is woven, the female attendant conveys it to a "taking-in-room," where it is examined. Credit is given to her for the piece, and should any flaws occur in it, they are noted down; a mark is then made on a tally, which the woman produces, and at the end of the week she is paid according to the number of pieces taken in.

These details refer to Mr. Orrell's mill at Stockport, which the editor visited some years ago. In Messrs. Ackroyd's power-loom shed at Halifax, which he also visited, there were 17 rows of power-looms, each containing 48 looms. A large proportion of the looms were mounted with the Jacquard apparatus, one set of cards serving two looms.

SECTION V.—CARPET WEAVING.

In former times the floors of houses were covered with hay, straw, or rushes. The first advance towards a carpet was made by plaiting the rushes into matting. In a country like England where wool was abundant, a coarse woollen cloth was spread on the floor of some of the rooms of the gentry. This was at first of one colour, and afterwards of various colours grouped into a certain pattern. As it is probable that the smooth turf suggested the use of a carpet, so the flowers which enamel the one may have suggested the ornaments for the other. It is to be regretted that the suggestion should have been forgotten in designing patterns for carpets, for instead of the beautiful and simple objects which adorn the turf, we often see on carpets architectural scrolls, and heavy decorations, portraits of animals, &c., on which it would be impossible to walk, if the real instead of the simulated objects were placed on the ground. Design in the useful arts when regulated by common sense and propriety, without which good taste cannot exist, would not place on the floor decorations intended for the walls, or for the vertical lines of a building. The carpets of Turkey and Persia (which probably present to us the most ancient mode of carpet weaving) do not err in this respect; they are soft in texture, pleasant alike to the feet and to the eyes, presenting not a pattern, but a harmonious shading or grouping of colour, not of light and bright colours, (such as would be soiled, and would require the absurd anomaly of another carpet of inferior material placed upon it to preserve it,) but of dark, unobtrusive colours, which give repose to the eye, and do not divert the attention from the lighter and more brilliant decorations of the walls and ceilings, which, not being trampled on, are not liable to soil, and indeed require to be light and bright, in order to reflect the light of the room, and thus contribute to its cheerfulness.

The manufacture of carpets is said to have origi-

nated in Turkey and Persia; it is also of ancient date in India and Tunis, which countries, during a long period, supplied Europe with this article of luxury. In the middle ages, carpets were first used before the high altar and certain parts of the chapter in abbeys. Bed-side carpets are noticed as early as 1301; and in drawings of the 15th century, the royal throne is represented as being surrounded by a carpet of a simple flower pattern. Turkey carpets before the communion table are noticed in the reign of Edward VI., Elizabeth, and James.

The manufacture of carpets is said to have been introduced into Europe by the French, in the reign of Henry IV. The largest manufactory was that of Chaillot, or the royal manufactory of *La Savonière*, or the "Soap House," situated about a league from Paris. The carpets were of wool, and were worked in the manner of velvet, as in the modern Wilton carpet. This method of carpet weaving was introduced into London about the year 1750, by two workmen, who had left Chaillot in consequence of some dispute, and came to England for employment. They were encouraged by Mr. Moore, to whose assiduity the manufacture in this country is principally owing; but after a time these men left Mr. Moore, and in company with one Parisot, under the patronage and with the pecuniary assistance of the Duke of Cumberland, established a manufactory at Paddington, and afterwards at Fulham. Mr. Moore, however, was a formidable rival to the scheme; his manufactory flourished, and in 1757 he obtained a premium from the Society of Arts for the production of the best imitation of a Turkey carpet. The Turkey carpet, however, consumes a large quantity of materials, and is slow in being produced. Hence it is an expensive article. The introduction into this country of other and cheaper modes of weaving carpets, led to a general taste for this luxury, so that a room not covered with a carpet was regarded as unfurnished. On the continent of Europe this taste has never become common; and the inlaid floor polished with wax is still continued in the houses of the wealthy, while in poorer houses the plain deal boards remain without a covering.

There are chiefly six varieties of carpet in this country, viz. the *Axminster*, the *Venetian*, the *Kidderminster*, the *Scotch*, the *Brussels*, and the *Wilton*. These names, however, do not point out either the present or the original seat of manufacture, for the Axminster carpet is similar to the Turkey, but even more expensive: the one being made of worsted, the other of woollen yarn. The manufacture of Turkey carpets at Axminster in Devonshire, and at Winfield in Yorkshire, ceased about 25 years ago. Venetian carpets, made in narrow widths for staircases and passages, did not originate in Venice, and are not even made there. The Kidderminster carpet presents an example of *double-weaving* or *two-ply*, and is produced by incorporating two sets of warp, and two of weft yarns; such are called in America *in-grain* carpets. They are manufactured not only in Kidderminster, but in Yorkshire, and in Scotland. Scotch carpeting is the same as Kidderminster, but it includes a *three-ply*, or *triple in-grain* carpet; also manufactured in Yorkshire and Kidderminster. Brussels and Wilton carpets are also manufactured at Kidderminster.

For the manufacture of woollen or worsted yarns used in carpet-weaving, we must refer to the article WOOL. Some carpet weavers receive their yarns "in the grease,"—that is, spun, but not dyed, and they dye them previously to weaving. Some factories, however, perform all the processes required for the preparation of their carpet yarns. In Eastern countries the manufacture is carried on in pastoral districts, where it serves to fill up the leisure of cultivators and their families. The loom consists of two upright pieces of wood fixed at some distance, supporting a roller at the top, on which the warp or chain is wound, and a second roller about 2 feet from the floor, upon which the finished carpet is wound. The work is done entirely by hand: coloured worsted is tied in short lengths, each tie passing across the face of two warp threads round the back, and has the ends brought up between them. When a row of ties has been completed, a shed is formed in the warp, and the shoot is passed across from right to left and returned, binding the whole together, and is beaten down to a horizontal level by hand-beaters. In the Great Exhibition there was a carpet from Cashmere, made entirely of silk, and containing at least 10,000 ties in every square foot. It was remarkable for the beauty of its texture, and the softness and harmony of its colouring.

The *rug-loom* or *Turkey carpet-loom* of Europe is similarly constructed. It consists of two beams, one above another, as in the above arrangement; the warp or chain, of strong linen yarn, is mounted on the upper beam, and brought down through headles to the lower beam. The weaver is seated as at the common loom, and having thrown a weft thread once or twice across, he fastens to every thread of the warp, by a peculiar twist, a small bunch of coloured yarn, varying the colour according to a pattern before him. One row being completed, he passes a linen weft through the web, and drives it well up, so that the small bunches or tufts may be held securely. Another row of tufts is then twisted in, according to the pattern. In this way narrow breadths of carpet are produced, which being placed side by side and joined together, form one large carpet; the surface is then sheared, so as to produce one level. *Rugs* are formed by a similar contrivance. A number of coloured worsted yarns are hung over a bar to the right of the weaver, who, taking the end of one yarn, attaches it to the chain, cuts it off to the proper length, then twists in another, which he severs in the same manner, and in this way forms a row of tufts across the warp; he next passes a shoot or two of weft, and then drives up the weft with considerable force. Young girls are employed in rug-making; their nimble fingers tie in the coloured worsteds with great rapidity, and, from constant practice, they know which particular colour to use at any particular spot, without referring to the pattern sheet.

Venetian carpets are also produced at a common loom. The pattern is formed entirely by the warp, the weft being concealed: the warp consists of a heavy body of worsted, arranged so as to form stripes, which shade off imperceptibly from dark to light. By using shoots of different kinds plaids and checks may be formed, and by a proper arrangement of the headles a twilled or dotted pattern may be produced. *Dutch* carpeting is similar to plain Venetian, but coarser, cow-hair being sometimes introduced.

The Kidderminster, or Scotch carpet, has a worsted chain and a woollen shoot, and consists of two distinct webs incorporated into each other, so as to produce the pattern. Each cloth is perfect in itself, so that if one cloth were carefully cut away, the other would appear like a coarse baize. Both cloths are woven simultaneously, one or other cloth being brought up to the surface as required to produce the pattern in any particular part. There is always a tendency to the formation of stripes in this species of carpet, since the pattern is produced by one set of coloured stripes crossing another, and much skill is required in the arrangement of these stripes. Full colours are obtained by crossing the warp with similarly coloured weft, and any particular colour can be concealed by sending the threads to the other web. In general the warp is not much varied, variety of colour being produced by the weft. For example, the weaver has often a warp of two colours only, such as white and maroon: across the white he may throw white, drab, fawn, light-green, and yellow, to form a fancy or shaded ground. With the maroon warp he may use two or three different shades of weft consisting of full greens, scarlets, crimsons, blues, and olives. The warp shows very little upon the face of the carpet. A two-ply Kidderminster, from the nature of its construction, has a right and a wrong side, the colours being reversed. If, for example, the colours be green and red, the green portions on the one side will be red on the other, and *vice versâ*. A Jacquard apparatus is attached to the loom for regulating the pattern, and the weaver has a variety of shuttles, containing wefts of different colours. The pattern-designer in this style must arrange his figures, and dispose of his colours, so as to conform to the restrictions under which the weaver is placed. The three-ply carpet allows of greater variety and brilliancy of colour than the double carpet, while its great thickness and comparative cheapness are great recommendations. It is largely manufactured at Kilmarnock.

A variety of carpet called *British* or *damask Venetian*, is a kind of mixture of Venetian and Kidderminster. It resembles Kidderminster in the weaving, but in Venetian the warp only is seen, while in Kidderminster the shoot is chiefly at the surface. This variety is also called *French*, or *tapestry carpeting*.

In Brussels carpet there is a linen web, enclosed in worsted yarns of different colours, raised into loops to form the pattern. The structure of this carpet is represented in Fig. 2323, in which the small black dots represent the ends of the shoot, and the double waving lines two separate sets of linen warp or chain: between the black dots, or between the upper and under shoot, is the worsted yarn, usually

Fig. 2323.

consisting of 5 *ends* of different colours; each end may consist of 1, 2, or 3 threads, according to the quality of the carpet. Supposing there are 2 threads to each end, which is the common number, there will be 10 threads bound into the carpet every time the warp is shed. The pattern is formed by bringing to the surface at any particular spot, such of the five coloured yarns as are required, and they are formed into loops by being turned over wires which are represented in the figure by the large black dots. As the coloured threads are taken up very unequally, they are not wound upon one beam, but are placed separately upon separate bobbins, arranged in frames at the back of the loom, with a small leaden weight or bullet attached to each bobbin, as in Figs. 2324, 2325, which show a bobbin nearly empty, and one full of yarn, to keep the worsted slightly stretched. The bobbins are mounted in pairs, as shown in Fig. 2326, with a wire or *spit*, also called a *benchwire*, passing through them, and resting in grooves upon the frame. Such is the arrangement at Kidderminster. At Wilton, the arrangement is somewhat different, and will be explained by referring to Figs. 2327, 2328, 2329.

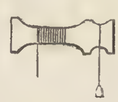


Fig. 2324.

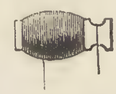


Fig. 2325.

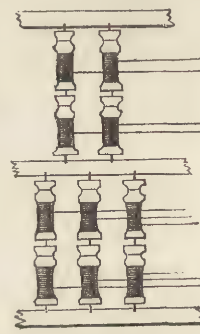


Fig. 2326.

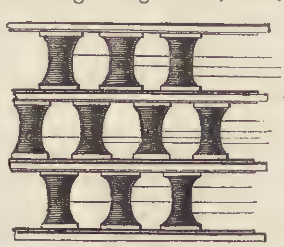


Fig. 2327.

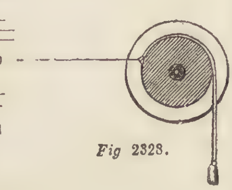


Fig 2328.

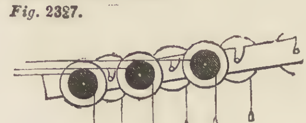


Fig. 2329.

The loom itself is represented in Fig. 2330. In such a loom there are as many frames as there are colours; the number of bobbins in each frame is

regulated by the width of the carpet. The usual width is three-quarters of a yard, in which case there are 260 bobbins to each frame. But if the carpet be a yard wide, the number of bobbins is 344. From each bobbin, the ends are carried through small brass eyes, called *males*, or *mails*, attached to fine cords, one eye and one cord for each end. Each cord is passed over

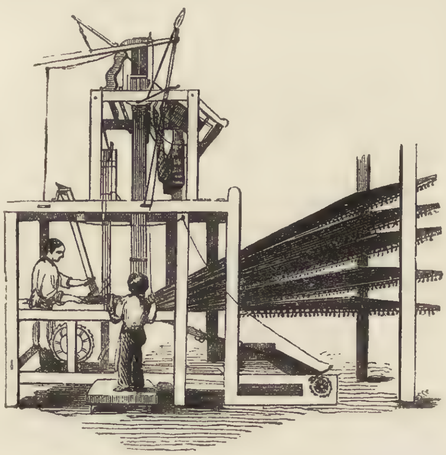


Fig. 2330. BRUSSELS CARPET LOOM.

a pulley fixed above the loom, and is brought down again by the side of the loom, and is fastened to a stick. For a three-quarter carpet, there are 1,300 of these mails, cords, and pulleys to each loom; the pulleys are arranged in a frame or box at some distance above the mails. It is evident, that by pulling the cords as they hang at the side the mails or brass eyes will be raised, and with them the worsted ends which pass through them; but if all the ends are raised simultaneously, no pattern will be formed; an arrangement must therefore be made beforehand, to pull such of the 1,300 cords as will raise the colours required in each particular spot, for which purpose, in the absence of the Jacquard apparatus which is now commonly used, the draw-loom already referred to in a previous section is employed. We have seen it in use within a few years at Kidderminster, arranged in the following manner. Those cords which will raise to the surface certain yarns required for the pattern are bound together into a *lash*. One lash is necessary for every set or row of colours that has to be drawn to the surface, and the lashes are taken in regular succession until the pattern is complete. The number of these lashes is often large; as many as 320 may be required to make out a pattern a yard long: this being completed, the succession of the lashes is repeated for the repetition of the pattern. The lashes are pulled by an assistant boy or girl, called the *drawer*. Supposing the loom to be at work, the drawer takes the first lash, and gently draws forward the 260 cords, whereby they are separated from the others. He then pulls the lash with considerable force, and thus raises such of the 1,300 ends as are required to be raised for the pattern; inserting with the other hand, under the raised ends, a light wooden board, or *sword*, about 3 feet long, and 5 inches wide; it is set up on edge, so as to retain the raised ends about 5 inches above the surface. The drawer then lets go the lash, and the weaver inserts into the *bosom*, or opening formed by the sword, a round wire through the whole width; the drawer takes away the sword, and the weaver depresses one of the treadles, whereby one of the linen warps is raised above the surface; while the other warp, together with all the remaining worsted ends, is depressed. The shuttle with a linen shoot is then thrown in, the weaver depresses the other treadle, whereby the worsted and the warp before depressed are now raised, and then throws in a second or under shoot, forcing the materials closely together with a heavy batten. This completes the weaving of one wire; a second lash is then drawn, and the work proceeds as before. When a number of wires have been thus woven in, they are drawn out one at a time with a hook inserted into a bow at the end of each wire; but the last five or six wires must be left in, or the worsted loops would be drawn down flat, and show the linen web. Sixty wires form what is called a *set*.

The Wilton carpet, called *Moquette* by the French, differs from the Brussels in the form of the wire, and in the method of removing it from the loops. The wire used for the Wilton carpet has a groove in the upper surface, as in Figs. 2331, 2332, and the edge of a sharp knife being drawn along this groove, the wire is thus liberated. The worsted loops thus cut form a pile or velvet, the structure of which is represented in Fig. 2304. By increasing the size of the wire, the Wilton carpet can be increased in thickness or quality. The quality of Brussels and Wilton is measured by the number of wires included in the inch; the usual number is 9 for Brussels, and 10 for Wilton, but whatever number is adopted, great uniformity must be observed, or the pattern would not match when the breadths were joined together at the sides. As a guide to the weaver, a bell is made to ring when 64, 80, or 90 lashes have been woven; he then ascertains by a measure whether the required number of lashes measures a quarter of a yard; if too short, he repeats the last lash, or omits it if too long. The length of a piece of Wilton carpet is 36 yards. After the weaving, the nap or pile is sheared after the manner of broadcloth, [see Wool,] the action of the knife being assisted by circular brushes.

Fig. 2331.

Fig. 2332.

It will be seen from the foregoing details, that in the production of the Brussels carpet, only one of the 5 sets of coloured yarns appears on the surface at any particular spot, the other four being concealed in the web. Mr. Whytock has effected a great economy in this respect. It occurred to him that if for the 5 coloured yarns he could substitute one yarn dyed of the requisite colour at different places, he would be able to get rid of all the apparatus for producing the pattern, the web being worked with

only one body like a simple velvet. His arrangement for dyeing the warp-threads is as follows:—The yarn is arranged in regular coils on the surface of a large hollow drum, Fig. 2333, on a horizontal axis; the surface of the drum is covered with blanket,

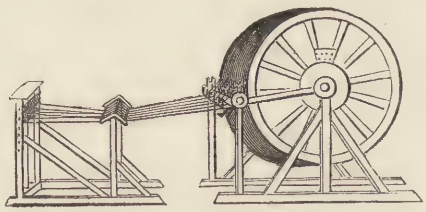


Fig. 2333.

and on this is oil-cloth, to keep the blanket clean. The dye is applied to the yarn by means of rollers; each roller is about 9 inches in diameter, and ½ inch wide, and works in its own colour-trough, supported by a low carriage. To apply the colour to the yarn, the carriage is moved across the cylinder, when the roller is made to press by means of springs against the coils of the yarn, thus imparting to them a coloured streak without any pattern, a portion of each coil being stained to an extent equal to the printing surface of the edge of the roller. When the yarn is unwound, the coloured marks thus produced will be at equal distances along the length of the yarn. One impression being made, the cylinder is turned round through a space equal to the breadth of the impression left by the roller; and then, if the pattern require a change of colour, another roller charged with another colour is applied across the yarns so as to make a second streak by the side of the first. By a repetition of this process, the cylinder of yarn is completely covered with streaks, the colours being in the order required by the pattern in the woven fabric. The yarns are next removed from the cylinder, together with the oil-cloth covering, upon which they are kept extended until the colours are dry. The yarns are then made up into hanks, and the colours fixed by steaming. [See Calico Printing, Fig. 416.] They are next washed in water, to remove the gum or paste with which the colours are mixed up, and after being dried they are wound upon bobbins for warping. In the mean time another set of yarns is wound upon the cylinder, and dyed by a similar process, and in this way the whole of the warp-yarns are prepared. The party-coloured threads are next arranged side by side to form the warp. As each yarn forms several coils round the cylinder, the order in which the colours succeed each other on each yarn will be repeated at intervals along a length of each yarn equal to the circumference of the cylinder. The succession of colours is determined by a design paper containing the pattern, ruled with squares, the lines being numbered along the top and down the length, and containing the entire figure of the pattern, so that, whatever number of squares the design paper occupies, the circumference of the cylinder must be divided into a like number of equal parts, or a multiple thereof, such as the double and the treble. In applying the colour to the yarns, a narrow black line is impressed across them as a common starting-place for all the yarns, and this black mark is to be repeated at the points where the repetition of the pattern begins. All the yarns being properly adjusted, the black marks will range in a straight line across the breadths of the warp, and the pattern will be correctly made out by the party-colours of the yarn. To keep the colours in their places, a clamp, Fig. 2334, is applied across the warp, which is shifted across as

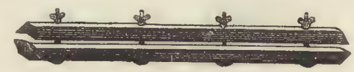


Fig. 2334.

the weaving proceeds. The weaving is conducted after the manner of plain weaving, without the assistance of the complicated apparatus required in figure-weaving. When the weaver has woven one length of the pattern, he moves the clamp to the next black line. If the black marks which form it do not range together, some of the warp threads are gently pulled and adjusted, and the clamp is screwed fast as before. If the warp be wound upon a beam before it is placed upon a loom, the clamp is not required in weaving, but only in beaming; but when the warp proceeds at once from the bobbin to the loom, the clamp is used.

Some years ago, a plan was introduced for the manufacture of carpets, rugs, &c., by cementing a nap or pile to plain cloth without any kind of weaving being used. For this purpose a number of threads or yarns of twisted wool, cotton, silk or mixtures of these materials, are warped upon a beam, Fig. 2335, supported at one end of a frame, and weighted with friction cords to keep the yarns stretched. The ends

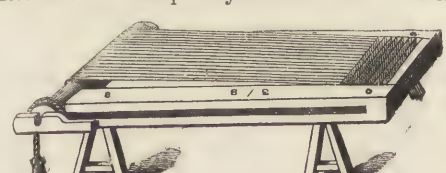


Fig. 2335.

of the yarns are drawn forward and attached securely to the front rail of a frame. The workman has a number of strips of metal of the same size, somewhat longer than the width of the intended fabric, but their width is equal in height to its pile or nap. The man first places a single strip beneath the warp, and, drawing it up to the end, and parallel with the front rail, he places it upon its edge, and inserts its two ends into grooves in the sides of the frame, whereby the strip is prevented from rising up; he next places the second strip edgeways on the upper side of the warp, and depresses the threads evenly between the two strips, inserting the ends of the second strip into side grooves, as before: the third strip is put under the warp, the fourth strip upon the warp, and thus the work proceeds until the frame is full, when the warp will be so arranged within the strips as to pass first under and then over each succeeding strip, as in Fig. 2336. The surface being brushed or combed, to bring the fibres into contact, a quantity of solution of India

rubber, or other cement, is spread over it, and a piece of canvas or coarse cloth is laid on to form the back,

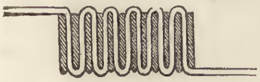


Fig. 2336.

a heated roller being applied to promote the union. When the cement is dry, the frame is turned over, and the metal strips are cut out, as in the Wilton carpet. A soft pile is thus produced without any pattern, unless yarns of different colours be introduced into the warp so as to form stripes; or the yarns may be first printed, as in Whytock's process. For a figured pattern, the following is the arrangement:—Two frames, containing wire gauze, or perforated zinc, (4,000 perforations to the inch being sometimes used,) are placed exactly over each other vertically, the distance apart being only regulated by the height of the room. The pattern or picture which is to be copied is arranged in the same way as the patterns used for worsted-work, the colours being contained in small squares. For some patterns, however, a tracing may be made on the top side of the upper frame. A workman then passes threads of dyed wool through the corresponding holes in the top and bottom frame; the upper ends of the threads guiding him in the choice of shade and colour, the space between the frames being filled with a compact and apparently confused mass of worsted thread. By another contrivance, a number of frames are fixed upright, at equal distances apart, in a stand, as in Fig. 2337. A piece of canvas, such as is used for worsted-work, varying in fineness with that of the

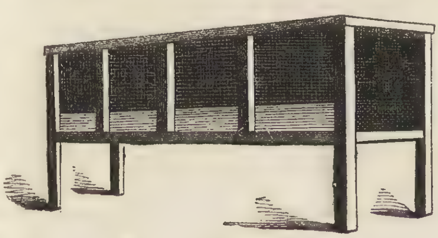


Fig. 2337.

materials used, is stretched within each frame. The workman has a pattern-paper before him, or the pattern may be sketched on the canvas itself. A needle, containing the worsted or other yarn, is then drawn through a hole or mesh in the canvas at one end, and then through corresponding holes in the canvas of the other frames; it is usual to begin at the lower corner hole, and to work successively through each hole of the lower holes of the canvas. The next row of holes is then worked, and so on; and the threads or yarns between the frames must be drawn equally tight, so as to lie smooth and even. When all the holes are filled, the spaces between the frames will be occupied by long quadrangular masses of yarn. This collection of yarn is next introduced into a case open at both ends, Fig. 2338, but composed of parts held together by screws, so that the yarn may be introduced by removing the top side. A solid ram or piston fits into one end of the case, for the purpose of forcing out portions of yarn as they are required. A solution of India rubber, or other cement, is applied to the fibres at one end of the case, and when dry, a quantity of

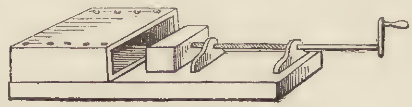


Fig. 2338.

yarn, equal to the length of the pile or nap, is forced out of the case by means of the piston. Such a length is then cut off with a sharp thin knife, as in Fig. 2339; the ends of the yarn left in the case are again coated

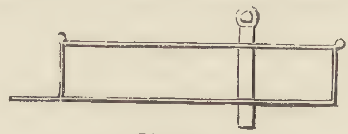


Fig. 2339.

with cement, another portion is protruded and cut off, and in this way the whole mass of yarn may be cut up into slices, which may afterwards be cemented to rough canvas, or to other fabrics. It is evident that each portion or slice is a repetition of the same pattern. The productiveness of this arrangement is also extraordinary; with the two outer frames five feet apart, as many as 480 slices or copies of the pattern have been obtained. The pile can be cut to any length, from the eighth of an inch upwards. When a laid nap is required, the ends of the case from which the section is made are on a bevel, the end of the piston is also on a bevel; so that each slice will be protruded and cut in an angular direction, and when cemented, will produce a laid nap. Another method of forming a napped surface, is simply to wind the thread or yarn spirally round thin strips of metal, as in Fig. 2340; and a number of such covered strips being packed side by side in a frame, and the upper surface covered with cement, and some coarse fabric for a back, when the whole is dry, the strips can be cut out as already explained.

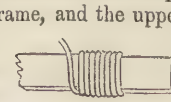


Fig. 2340.

The nap for hats and bonnets prepared in this way may be at once cemented to them.

There are various methods of manufacturing matting from straw, rushes, and other grassy stems of plants. Russia matting or bast is, however, made from the inner bark of the lime-tree, while the fibrous covering of the cocoa-nut furnishes a material of great strength and utility for matting. The materials for door-mats are very numerous; they may be rope, hair, basket-work, straw, sheep-skin with the wool on, goat-skin, tow, &c. Untwisted rope-yarn is also employed, woven into coarse canvas, and then cut so as to present a brush-like surface.

The term *tapestry* is usually applied to fabrics composed of wool or silk, in some cases enriched with gold and silver, woven or embroidered with figures, landscapes, or ornamental devices. The French word *tapis*, from which it is derived, although commonly applied to carpets, is also used to designate other figured cloths employed for covering the walls of

apartments, (which is the proper application of tapestry,) and also as the covering of tables, from which latter use, probably, arose the expression "on the tapis," applied to subjects under discussion. The early method of working tapestry was with a needle, the wool being worked into a coarse kind of canvas; the finer kinds were embroidered on a silken fabric. As early as the 14th and 15th centuries the art of weaving by the loom, in the *haute lisse* or high-warp style, was practised in the tapestries of Flanders, and perhaps in those of England. In the *haute lisse*, the frame containing the warp-threads is vertical, and the weaver works standing; in the *basse lisse*, on the contrary, the warp-frame is horizontal, and the weaver sits to his work. In the basse lisse the painting to be copied is placed beneath the threads of the warp; the weaver carefully separates the threads with his fingers so as to be able to see a portion of his pattern, and then with a shuttle called a *flûte*, containing silk or wool of the required colour in the other hand, he passes it into the shed formed by depressing the treadles, worked in the usual way. The weft, thus introduced, is driven up to the finished portion of the work, with the teeth of a box-wood or ivory comb. In this kind of weaving the face of the work is downwards, so that the weaver cannot examine it until it is removed from the loom, a circumstance which probably led to the disuse of the basse lisse. In the haute lisse the loom consists of two upright side-pieces, with large rollers placed horizontally between them, the warp, usually of twisted wool, being wound on the upper roller, and the finished web on the lower one. The cartoon or pattern sheet is placed vertically behind the back or wrong side of the warp, and the principal outlines of the pattern are sketched upon the front of the warp, the threads of which are not so close as to prevent the artist from seeing the design between them. The cartoon is now removed to such a distance from the warp, as to allow the weaver to stand in the space between, and he works with his back to the pattern sheet, so that he must turn round when he wishes to inspect it. The side pieces of the frame contain the means for forming a shed in the warp threads for the passage of the weft; a reed or comb, or a large needle, called an *aiguille à presser*, being used to force home the weft. As in the case of the basse lisse the artist works at the back of the fabric, but by walking to the other side of the frames he is able to inspect the work and correct defects. The progress of the work is almost as slow as in working with a needle. The breadths of tapestry are united into one picture by fine-drawing, and so skilfully that no seam is to be perceived. At the present day, however, the frames are made so wide that the largest pieces are woven without joining.

Section VI.— On Lace and Bobbin Net.

Lace is a kind of net-work of threads of gold, silver, flax, or cotton, forming a transparent texture. The word is said to be derived from the Latin *lacinia*, the guard hem or fringe of a garment. The origin of this delicate fabric is not known. It seems to have been worn by the Grecian and Roman ladies. It was in use at an early period in Venice, and the north of Italy, and is said to have been introduced into France by Mary de Medecis. It was known in England in 1483, in which year it is included in a list of articles not allowed to be imported; but as pins which are required in lacemaking were not used in England till 1543, the lace must have been of a coarse kind. The lace manufacture is said to have been introduced into this country by some refugees from Flanders, who settled at Cranfield in Bedfordshire. In 1640, the lace trade was flourishing in Buckinghamshire, and in 1660 a royal ordinance was passed, establishing a mark on the thread lace exported from this country.

Pillow or *bobbin-lace*, the original manufacture, was usually made of thread or silk woven into the net with hexagonal, octagonal, &c. meshes. It was afterwards ornamented with a thicker thread called gimp, so interwoven with the meshes as to form flowers and curved designs. This kind of lace was made on a hard, stuffed, pillow or cushion, covered with parchment, on which the pattern was drawn. Each thread was wound upon a bobbin, a small round piece of wood, with a deep groove in the upper part for retaining the thread. To form the meshes, pins were stuck into the cushion and the threads woven or twisted round them. The pattern on the parchment indicated the spots for the insertion of the pins, and also showed the place for the gimp, which was interwoven with the fine threads of the fabric. The work was begun at the upper part of the cushion by tying the threads together in pairs, each pair being attached to a pin. Bobbins were allowed to hang down by their threads on different sides of the cushion, but at the commencement of the work they were all arranged on one side, and were brought to the front side, two pairs at a time, and twisted together. The woman, holding one pair of bobbins in each hand, twisted them over each other 3 times, so that the threads of each pair became twisted together or round each other, so as to form the sides of the mesh. The adjacent bobbins of each pair were next interchanged, in order to cross these threads over one another to form the bottom of the next. Supposing the four bobbins to be marked *a, b, c, d; a* is twisted round *b*, and *c* round *d;* these in order to cross *b* and *c*, are interchanged, so that *a* and *c*, and *b* and *d* come together; the next time the twisting is performed these pairs of thread will be combined together. As the meshes or half meshes are made, they are secured by pins to prevent the threads from returning. The four bobbins *a, b, c, d,* being done with for the present, are put on one side of the cushion; the two next pairs are then brought forward, twisted, and crossed in the same way. These operations are repeated until a row of meshes is formed, sufficient for the breadth of the intended piece of lace; the bobbins are then worked over again to form another row. As many as from 48 to 60 bobbins are required for every inch of breadth, and only one mesh is made at a time. A piece of lace one inch wide, with 50 threads per inch, will have 25 meshes in the breadth, or 625

meshes in each square inch of length, or 22,000 meshes in the yard, while the cost of such a piece is seldom more than 1*s.* 8*d.*

The most celebrated laces have been enumerated as follows:—1. *Brussels,* the most valuable, and of which there are two kinds; *Brussels ground,* having a hexagon mesh, formed by plaiting and twisting four threads of flax to a perpendicular line of mesh; and *Brussels wire ground,* made of silk, of which the meshes are partly straight, and partly arched. In both cases the pattern is worked separately, and set on by the needle. 2. *Mechlin;* a hexagon mesh, formed of three flax threads twisted or platted to a perpendicular line or pillar. The pattern is worked in the net. 3. *Valenciennes,* an irregular hexagon, formed of two threads, partly twisted and platted at the top of the mesh. The pattern is worked in the net. 4. *Lisle,* a diamond mesh, formed of two threads, platted to a pillar. 5. *Alençon,* called *blond;* hexagon of two threads, twisted, similar to Buckingham lace, and is considered the most inferior of any made on the cushion. 6. *Alençon Point;* formed of two threads to a pillar, with octagon and square meshes alternately.

The lace represented in the portraits painted by Vandyke in the time of Charles I., and afterwards by Sir Peter Lely, and Sir Godfrey Kneller, in the succeeding reigns, is *Brussels Point,* in which the net-work is made by bone-bobbins on the pillow, and the pattern is worked with the needle. It is stated that the first lace ever made in this country was of this kind. "About a century since, the *grounds* in use were the *old Mechlin,* and what the trade termed the *wire ground,* which was very similar, if not identical, with the *modern Mechlin,* the principal article in the present French manufacture. The laces made in these grounds were singularly rich and durable; the designs of the old Mechlin resembled the figures commonly introduced in ornamental carving. Between seventy and eighty years ago, a great deterioration was occasioned by the introduction of the *Trolly* ground, which was exceedingly coarse and vulgar, the figures angular, and altogether in the worst taste. An improvement, however, took place about the year 1770, when the ground which is probably the most ancient known, was re-introduced; this was no other than the one still in partial use, and denominated the *old French ground.* About 1777, or 1778, quite a *new* ground was attempted by the inhabitants of Buckingham and its neighbourhood, which quickly superseded all the others; this was the *point ground,* which had (as is supposed) been imported from the Netherlands. From the first appearance of this ground may be dated the origin of the modern pillow lace trade; but it was not until the beginning of the present century that the most striking improvements were made; for, during the last quarter of the eighteenth century, the article, though certainly much more light and elegant from the construction of the ground, was poor and spiritless in the design. Soon after the year 1800, a freer and bolder style was adopted, and from that time to 1812, the improvement and consequent success were astonishing. At Honiton, in Devon, the manufacture had arrived at that perfection, was so tasteful in the design, and so delicate and beautiful in the workmanship, as not to be excelled even by the best specimens of Brussels lace. During the late war, veils of this lace were sold in London at from 20 to 100 guineas; they are now sold from 8 to 15 guineas. The effects of the competition of machinery, however, were about this time felt; and in 1815, the broad laces began to be superseded by the new manufacture. The pillow lace trade has since been gradually dwindling into insignificance."[1]

Honiton lace is made by placing a perforated pattern on a pillow, and then so twisting and interweaving the thread by means of pins, bobbins, and spindles, as to produce the required pattern. Simple sprigs and borders were formerly the only things produced, but at the present time the most beautiful and delicate fabrics are produced complete by sewing the hand-made patterns upon machine-made net. Pillow or thread-lace is also made upon a cushion, but it is distinguished from Honiton lace by having both the pattern and the mesh made by hand. British point, tambour, and Limerick laces are often successful imitations of Honiton and Brussels lace, and are produced in shawls, scarfs, court-trains, flouncings, &c. British point is made chiefly in the neighbourhood of London. Tambour is made at Islington, at Coggeshall in Essex, and at Nottingham. Limerick lace is peculiar to Ireland, and is a valuable source of industry in that country.

Lace is said to have been made by machinery so early as the year 1768, by a stocking-weaver of Nottingham, named Hammond. Being out of employ, the idea occurred to him, while looking at the pillow lace on his wife's cap, that such an article might be made by means of the stocking-frame. He appears to have succeeded in producing a machine which was called a *pin machine* for making single press *point* net, in imitation of Brussels ground. This machine is no longer used in England, but is in use in France in the manufacture of net called *tulle.* Hammond's success led other workmen to attempt lace-making by the stocking-frame, and in their leisure hours they amused themselves by trying to form new meshes on the hand, in the hope of producing a complete hexagon, a thing not as yet accomplished. The *warp-frame* for making *warp lace* was introduced in 1782, and from 1799 dates the first attempt to make *bobbin net* by machinery. By this means the stocking-weavers produced an inferior kind of lace with such facility that they could greatly under-sell the pillow-lace weavers, whereby the demand for lace was increased, and Nottingham soon became the centre of a new and thriving trade.

Concerning this period in the history of the lace-trade, it is remarked, in the Jury Report, Class XIX.: —"It has been matter of astonishment to see how quickly one inventor has succeeded another, and by simplifying or modifying his machines, rendered use-

(1) M'Culloch's Commercial Dictionary. Article LACE, by Mr. Robert Slater.

less those of his predecessor. It may be stated, that in none of the textile fabrics have there been so many combinations of machinery used to effect the purpose as in the making of lace, commencing with the stocking-frame, to which was added a Tickler machine; then the point-net machine, warp machine, Mechlin plait machine, and many others. All of these (except the warp machine) disappeared for the purpose of making lace, when the bobbin-net machine was introduced, and its capabilities for making both plain and ornamental lace became developed. The bobbin-net machine is so called, from the thread that makes the lace being partly supplied from bobbins, and partly from a warp."

No successful attempt to produce bobbin-net by machinery occurs previous to the year 1809, when Mr. Heathcoat patented a frame which is said to have been suggested by a workman employed in making fishing-net machinery; the idea occurred to him of making lace by means of warp and weft threads, by arranging the warp in parallel lines, and disposing the diagonal weft-threads upon small detached bobbins, arranged so as to pass round and twist with the intended warp-threads. The machine was successful, and so far affected the pillow-lace makers, that they formed themselves into a party, under the name of "Luddites," for the purpose of putting down by force the new invention. Mr. Heathcoat removed to Devonshire, and was successful in the production of machine-made bobbin-net. In 1823 his patent expired, and the manufacture revived at Nottingham, where the lace-frame soon rivalled and superseded in plain nets the productions of France and the Netherlands. The machine became the subject of frequent improvement, and in the year 1816 was worked by steam power. Lace became a general article of consumption; that which had been sold at 5 guineas a yard, fell to 1*s.* 6*d.*; quillings sold in 1810 at 4*s.* 6*d.* a yard, were vended of better quality at 1½*d.* Instead of smuggling French lace into England, English lace was smuggled into France, until the continental makers were allowed to protect themselves by using lace-making machines.

A piece of lace (such as that represented in Fig. 2341) will be found, on examination, to consist of a series of nearly parallel warp-threads proceeding in one direction, while the weft twists once round each warp-thread until it reaches the outer one, when it makes two turns, and then proceeds towards the other border in a reverse direction; by means of this double twist, and the return of the weft-threads, the selvage is formed. The effect of the twisting and interlacing of the threads is to form the straight and parallel warp-threads with the weft into regular six-sided meshes, as in Figs. 2342, 2343, which represent on an enlarged scale the production of the fabric by the union of three sets of threads, one set consisting of the warp-threads proceeding from the top downwards, in a waving line; the second set runs towards the right, and third to the left; the second and third being weft-threads which cross each other obliquely in the centre, between each two meshes throughout the series; in fact, one set of weft-threads draws the warp-threads to the right, and the other to

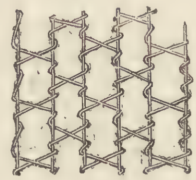


Fig. 2341.

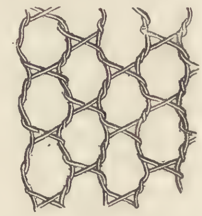


Fig. 2342.

the left. After the warp-threads have been laced twelve times by the weft-threads, the latter is moved sideways through one interval of the warp-threads. Lace-making thus differs form weaving in this, that the threads

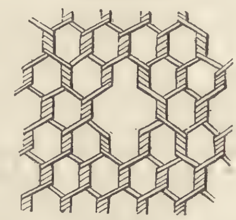


Fig. 2343.

of the warp are not alternately raised or depressed for the passage of the weft, but are shifted sideways to the next pair, to which they become united by means of the weft-threads, which also work in pairs, each of them entwining two individual threads at once.

The thread used in the lace-frame is wound upon the roller for the warp, and upon small bobbins peculiarly formed for the weft. In warping, the threads are first wound upon a reel, from which they are transferred to the roller or *thread-beam*, and which extends the whole length of the thread-beam; a portion of the reel and of the thread-beam is represented in Fig. 2344. The bobbins for the weft-threads are shown in Fig. 2345, in front, and in section. Each bobbin

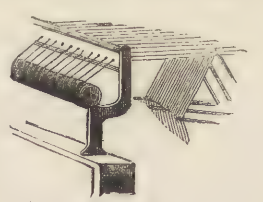


Fig. 2344.

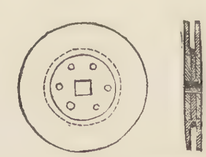


Fig. 2345.

is formed of two thin brass discs with a hole in the middle of each, riveted together, so as to leave a circular groove between them for the reception of the thread. In the centre is a square hole for receiving a square spindle or rod, for preventing the bobbins from turning round during the process of winding the thread. From 100 to 200 bobbins are thus spitted, and the thread is conducted from a drum through the slits of a brass plate, corresponding in number with that of the bobbins to be filled. On turning round the spindle which contains the bobbins, the drum revolves and delivers its thread, the surface of the table over which the train of thread passes is painted black, so that the winder immediately detects the breaking of a thread. As many as 1,200 bobbins may be required for one machine, and in order that the same quantity of thread, usually about 100 yards for each bobbin, may be wound upon each spitful, a

hand moving round a dial-plate is made to indicate the quantity wound.

Each bobbin is next inserted in a small iron frame, called the *bobbin-carriage*, Figs. 2346, 2347, where it is shown in the front and side section, the hole H in the carriage receiving the bobbin, the groove-borders of which fit the narrow edge *e e*, of the hole, and the spring preventing the bobbin from falling out, but allowing it to turn round and give off its thread when gently pulled. The thread is conducted through the eye at the top of the carriage.

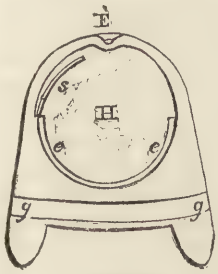


Fig. 2346.

Fig. 2347.

The working parts of the lace-frame are shown in the vertical section or end view, Fig. 2350; D, is the thread-beam containing the warp; and at the top of the frame is a similar roller D′ for receiving the finished work. The warp threads are extended in vertical lines between these two rollers. G G are guide-bars extending the whole length of the machine with slits in their edges, through which the warp-threads are conducted in two rows, one on each side, to the eyes *e e* of needles, one of which is shown separately in Fig. 2348. Each guide-bar, which contains a range of these needles, equal to one-half the number of threads in the warp, has a *shagging* or slightly shifting motion to the right or to the left, to allow the bobbin-threads to pass on the right or on the left of the warp as many times as is necessary to produce the twist. The number of bobbins, with their carriages, is equal to the number of the weft-threads, and as these have to pass through the narrow intervals of the warp-threads, they are arranged in a double line in two rows, as at C C′, Fig. 2350, on each side of the warp-threads. The bobbins are supported between the teeth of a sort of comb *c c′*, a portion of which is shown separately in Fig. 2349. The bobbin carriages are each furnished with a groove *g g*, Fig. 2350, for the reception of the teeth of the comb. There is one comb on each side of the warp, and the free ends of the teeth in the opposite combs stand so near to each other as to leave a space only just sufficient for the proper motions of the warp-threads between them; hence the carriages, in passing across through the intervals of the warp, reach the back bolts before they have entirely quitted the front ones. The carriages are driven alternately from one comb to another by two bars *b b*, and when one of the lines of carriages is pushed nearly across the intervals of the warp, the foremost of their projecting catches *c′ c′*, Fig. 2350, is laid hold of by a plate *p* attached to a horizontal shaft S, which pushes it quite through. The beam to which the combs are attached admits of being shifted a little sideways, either to the right or to the left; by which motion the relative position of the opposite combs is changed by one interval or tooth, so as to transfer the carriages to the next adjoining teeth.

Fig. 2348.

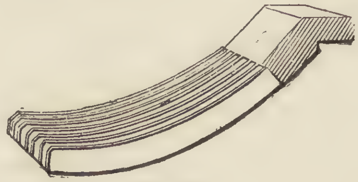


Fig. 2349.

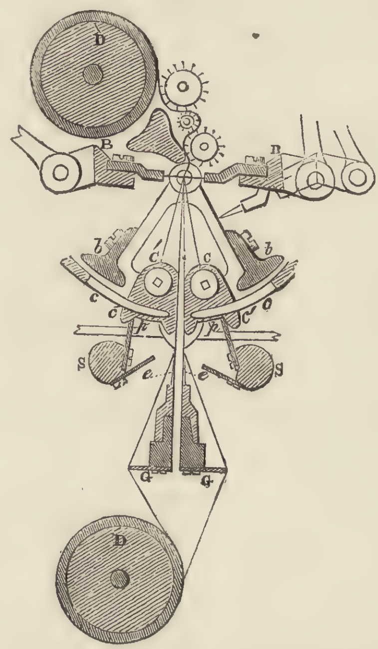


Fig. 2350. WORKING PARTS OF LACE MACHINES.

By this means the whole series of carriages makes a succession of side steps, to the right in one comb and to the left in the other, so as to perform a species of countermarch, in the course of which they are made to cross each other, and then again to twist round about the vertical warp threads, and thus to form the meshes of the net. After the bobbins have moved several times round about the warp threads, and entwined their threads with them, a point bar B B, Fig. 2350, containing a row of pointed needles, one of which is shown separately in Fig. 2351, falls between the warp and weft threads, and carries the interlacements of the latter up to form a new line of holes or meshes in the lace. Here it remains, while the other point bar makes a similar movement to produce a second line of meshes. Thus the whole working of the machine is a constant repetition of twisting, crossing, and taking up the meshes on the point bar. As the lace is finished it is wound upon the roller D′.

Fig. 2351.

The beauty of bobbin-net lace depends on the quality of the threads, and on the equal size and hexagonal shape of the meshes. The nearer the warp threads are together, the smaller are the meshes and

the finer is the lace. The number of warp threads in a piece one yard wide, may vary from 700 to 1,200. The fineness of the lace, or as it is called the *gauge* or *points*, depends on the number of slits or openings in the combs, and consequently the number of bobbins in an inch of the double tier. Thus gauge nine-points means nine openings in one inch of the comb. The length of work, counted perpendicularly, which contains 240 holes or meshes, is called a *rack*. Well-made lace has the meshes slightly elongated in the direction of the selvage. A circular bolt machine produces about 360 racks per week, working 18 hours a day, with two sets of superintendents. Bobbin net is usually sent into the market in pieces of from 20 to 30 or more yards in length. The breadth is variable. The narrow *quillings* used for cap borders, are worked in the same machine in many breadths at once. They are all united together by a set of threads, which are afterwards drawn out, and thus the quillings become so many distinct pieces.

The English machine-made net is now confined to *point net*, *warp net*, and *bobbin net*, so called from the peculiar construction of the machines by which they are produced. In a factory at Nottingham, visited by the writer, the machines employed are limited to the making of fancy net, both in wide pieces and in quillings, the thicker thread or gimp being wrought into the desired pattern by means of a Jacquard apparatus attached to the frame. When the desired pattern consists of a series of separate flowers, sprigs, &c., these are necessarily all connected by a single thread of gimp passing between them, which single thread is afterwards cut out by children, whose keen eyes and nimble fingers enable them to use the scissors with great precision and rapidity. Many establishments, however, produce only plain net, in which the pattern is afterwards worked by hand.

Nottingham has its pattern designers for lace, as well as Manchester for cottons. The lace pattern is drawn upon a block of wood, and then engraved in the same manner as a wood engraving, those parts of the surface being left in relief which are intended to make a mark. The block is slightly moistened with some coloured pigment, and is then impressed upon the net a sufficient number of times to cover its surface. The lace runner then fills up the pattern with her needle, the web being extended horizontally in a frame for the purpose. Of late years lithography has been introduced as a cheap substitute for engraved blocks, to the great advance of the trade. A Government School of Design established at Nottingham has had a highly beneficial influence in fostering the talent of native pattern designers.

Lace running is a domestic employment, and the young females engaged in it are not well paid. The depressed condition of the embroiderers arises in a great measure from the competition of the Belgians, who have acquired a superiority in this department. When the lace is embroidered it is carefully examined, and all defective parts are marked by tying them up in a knot; the piece is then handed over to women called *lace menders*, who have a method of perfectly restoring the damaged meshes. The lace menders are a much better paid class than the lace runners. The net is gassed before being embroidered; the bleaching or dyeing takes place afterwards; the dressing, rolling, pressing, ticketing, and making up, closely resemble similar processes described under CALENDERING.

The Jury Report contains a selected list of articles made by the bobbin-net machines; and also of the machines at present employed in the bobbin-net trade. Of the former are, *first*, black silk piece-net ornamented, shawls, scarfs, flounces, trimming-laces, blondes in white and colours, some entirely finished on the machines, others partly by machine, and embroidered afterwards; *secondly*, cotton edgings, laces, and insertions, linen laces in imitation of white pillow lace, muslin edging and laces, fancy piece-net, spotted net, and plait net, in imitation of the costly Valenciennes lace; *thirdly*, curtains in imitation of the Swiss curtains, bed-covers, and blinds, a branch of industry only introduced in 1846, but already so extensive as to employ more than 100 machines, and to elicit much excellence in design and texture; *fourthly*, silk and cotton, plain and Mechlin grounds, blonde, Brussels, or extra twist, a department employing 2,000 machines, and many thousands of work-people. The forms of machine by which all this variety of labour is accomplished are as follows: The "leavers," so called after John Leavers, the original constructor. By this machine most of the articles under the first and second divisions are fabricated. The "pusher," so called from having independent pushers to propel the bobbins and carriages from front to back, instead of pulling or hooking them as in other arrangements. Shawls, scarfs, flowers, &c. of superior quality, are made by this machine, and require to have the pattern traced afterwards with a thick thread. The "circular," so called from the bolts or combs on which the carriages pass being made circular, instead of straight, as in the straight-bolt machines. The curtains, imitated from the Swiss, are made by this machine, as are various descriptions of plain, spotted, and fancy nets. "Traverse warp machines" are employed to a limited extent. They are so called from the warp traversing instead of the carriages, and are principally used for spotted lace, blonde edgings, and imitation thread laces.

Such are the machines employed in the bobbin-net trade; but there is another and a very important class of machines, called warp machines, extensively employed in the lace trade. There are four persons for whom this invention is claimed (about the year 1775), one of whom was Vandyke, a Dutchman,—hence the first articles manufactured, which were silk stockings with a blue and white zigzag pattern, were said to have the "Vandyke stripe." For the common stocking frame but one thread is requisite, while for the warp a thread for each needle was employed,—hence it derived the name of warp machine. About 1784 a Nottingham mechanic considerably improved the warp frame by the application of the rotary motion and the cam wheels to move the guide bars, which

are still known in the trade as Dawson's wheels. The improved machine was, and still is, used for making officers' sashes, purses, &c. In 1796 a new fabric was produced from the warp machine, and employed for sailors' jackets, pantaloons, and other articles, and that fabric still known under the name of "Berlin" is largely employed in the manufacture of gloves. Warp machines were the first which produced ornamental patterns on lace, such as spots, bullet-holes, &c.; these had been previously embroidered or tamboured by hand. The application of the Jacquard apparatus to the warp machine was an important step taken by Draper of Nottingham in 1839, and led to the production of a new and elaborate class of goods by this means. Latterly the twist machine has produced similar goods, and has in a great measure supplanted the warp. So great have been the improvements of late years in the English methods of dressing lace, that it is now considered little, if at all inferior to the best specimens from Lyons. Many new kinds of manufacture have been produced by the warp of late years, such as elastic woollen cloth for gloves, and even velvet and plush made elastic for the same purpose. Velvet, in combination with lace, and many other novel forms of weaving, are also the fashion of the day.

Section VII.—On Hosiery, or Stocking-Frame Weaving.

In the process of knitting, whether by hand or by machine, a single thread is entwined in such a manner as to produce a tissue resembling cloth. Netting resembles knitting, inasmuch as the composition of a net is also due to a single thread; but in a net, this thread is tied into hard knots at those points where it crosses upon itself, and thus forms distinct meshes; while in knitting the thread forms a succession of loops, which run into each other without knots. An injury to one mesh in a net need not affect any of the other meshes; but the breaking of one loop in a knitted fabric, leaves the whole tissue liable to come unlooped. Knitting and netting are familiar occupations, much more easy to learn than to describe in words. Netting is an ancient invention, nets being referred to in the prophetical writings of the Old Testament. Knitting is of more recent date. The knitting of stockings is supposed by Savary to have been invented in Scotland in the 16th century, from the circumstance that when the French stocking-knitters in 1527 became numerous enough to form a guild, they chose St. Fiacre, a native of Scotland, for their patron saint. There is also a tradition, that the first knit stockings seen in France were brought from Scotland. Other writers adopt the opinion, founded on a passage in Howel's "History of the World," (printed in 1680–85,) that the art of knitting stockings came from Spain. He says that "Henry VIII. wore ordinary cloth-hose, except there came from Spain, by great chance, a pair of silk stockings. King Edward his son was presented with a pair of long Spanish silk stockings, by Sir Thomas Gresham, his merchant, and the present was taken much notice of. Queen Elizabeth, in the third year of her reign, was presented by Mrs. Montague, her silk woman, with a pair of black knit silk stockings, and thenceforth she never wore cloth any more." This information is confirmed by Stow, who names the Earl of Pembroke as the first nobleman who wore worsted knit stockings. In 1564, William Rider, an apprentice of Master Thomas Burdet, having seen in the shop of an Italian merchant a pair of knit worsted stockings from Mantua, borrowed them, and made a pair exactly like them, and these are said to have been the first stockings of woollen yarn knit in England.

Not long after the art became known in England, the knitting of stockings was adopted as a domestic employment. When Queen Elizabeth visited Norwich, in 1579, several female children appeared before her, some of whom were spinning worsted yarn, and others knitting hose from the same material. Not many years later an attempt was made to expedite the process by the aid of machinery. The history of the stocking-frame is rather difficult to trace; but there exists a picture in the Stocking Weavers' Hall, London, with the following inscription: "In the year 1589, the ingenious William Lee, Master of Arts, of St. John's College, Cambridge, devised this profitable art for stockings, (but being despised, went to France,) yet of iron to himself, but to us and others, of gold; in memory of whom this is here painted." The picture represents a man pointing to an iron stocking-frame, and addressing a woman who is knitting with needles by hand. The story of this William Lee, or Lea, is that he was a native of Woodborough, in Nottinghamshire; and that when at Cambridge he married, contrary to the statutes, and was on that account expelled from the University. His prospects thus destroyed, he found himself without means of support, except that derived from his wife's skill in knitting stockings. It then occurred to him that artificial fingers might be contrived for knitting many loops at once; and, having convinced himself of the possibility of this plan, he devoted much time and labour to its accomplishment. When success at length crowned his efforts, he instructed his brother James in the use of the frame, and proceeded to make an application of his invention, first at Calverton, a village near Nottingham, and shortly afterwards in London. In the latter place he succeeded in obtaining the notice of Queen Elizabeth, who is said to have actually visited him in order to see him work at his frame. The Queen expressed her disappointment that he was making woollen instead of silk stockings, and refused to give him either a grant of money or a patent of monopoly, on the ground that the invention would deprive the poor of employment. About the year 1596-7, Lee succeeded in making plain silk stockings from a twenty-gauge silk frame. He erected nine frames, which were worked by apprentices, chiefly consisting of his relatives; who esteemed it so high an honour to belong to the new craft, that they wore their working needles, with ornamented silver shafts, suspended from a silver chain at their

breasts. Lee failed in procuring a patent; and some time afterwards, when Sully came to London, as ambassador for Henry IV. of France, he made Lee very splendid offers to induce him to remove himself and his machinery to France. The disturbed state of that country led him at first to decline the offer; but some years afterwards, finding that the King, James I., was even more unfavourably disposed to his invention than Elizabeth had been, he removed the whole of his machinery and workmen to Rouen, in Normandy. Having established his frames in that city, he went to Paris, and had the honour of an interview with Henry IV. Everything seemed to promise success; but the troubles consequent on the murder of the king destroyed Lee's prospects; he was proscribed as a Protestant, and was obliged to seek concealment in Paris, where he died in poverty and distress. Lee's brother, and all the workmen except two, returned to England. The two who remained were allowed to retain one frame; the other frames were brought to England, and one of them appears to have been sold to a person named Mead, in the city of London. The attempt which had been made by Sully to plant the infant manufacture in France, was also made by the ambassador from Venice in favour of that city, then the most commercial and manufacturing in the world. He paid Mead the sum of 500*l.* for the purchase of his frame and his personal superintendence of it at Venice. But as Mead could not make his needles, nor repair his frame, his work was soon brought to a stand. The Venetians also failed in their endeavours to copy the machine; and as Mead, at the expiration of his engagement, insisted on returning to London, the whole scheme of Venetian frame-work knitting was abandoned. This was about the year 1621.

After the return of Lee's workmen to London, they did not remain idle. Through their means the number of frames and frame-work knitters increased rapidly; so that early in the 17th century, the frame-work knitters resident in London, which was then the principal seat of the manufacture, formed themselves into a company, and petitioned Cromwell to constitute them a body corporate. The Protector does not appear to have paid any attention to this petition; but immediately after the Restoration it was renewed, and at length, in 1663, the petitioners obtained a charter, which came into operation in the following year.

This charter gave a great impetus to the trade in London and its neighbourhood; the prices of admission to the Company were low, and the number of applicants was large. The master, wardens, clerks, assistants and deputies were the only parties who were electors; and the assistants at the end of forty years were composed of frame-work knitters and of persons who had bought in for the sake of the vote. The Company had a large income, arising from the various fees, and from the sale of freedoms and livery; but as they were restricted from holding more than 100*l.* per annum, they managed to get rid of the surplus in feasts and gorgeous processions, such as were indulged in by other trade companies, to the great delight of the populace. The great day for these shows was, as at present, the 9th of November, when the Lord Mayor was installed. The trade had by this time extended to Leicester, Nottingham, and Derby, where the companies were governed by the laws of the London Company. These having been, on some occasions, rigorously exerted, misunderstandings arose, and attempts were made to throw off the authority of the metropolis. These attempts became successful in 1753, when a decree of the House of Commons virtually extinguished the monopoly. About 1756 Jedediah Strutt invented a machine for making ribbed-stockings, and with his brother-in-law, Mr. Wollatt, of Derby, took out a patent for the same. This improvement led to others, such as open-work mittens, and fancy articles in the stocking stitch. With this exception the stocking frame seems to have reached a nearly perfect state about the year 1714, and has continued up to the present time only to be worked by hand, not because it is incapable of the application of steam power, but on account of the abundance and cheapness of hand labour. Of late years circular hosiery frames have been introduced, by means of which ladies' skirts, stockings, and other articles, have been manufactured in great variety. The frames in the Great Exhibition, by M. Claussen and M. Jacquin, were nearly identical; they had vertical sinkers, eccentric depressers, and tucking pattern-wheels, and were capable of producing fabrics of great variety and beauty. The circular frames of M. Berthelot were of more complex structure: the sinkers were arranged in a horizontal position, and revolved with the frame; but these machines were capable of producing finer fabrics than the preceding, and with such materials as flax and silk.

Frame-work knitting is, for the most part, a domestic branch of industry. The stocking-weavers of Nottingham and its neighbourhood live, in general, in their own houses or rooms, and are furnished with frames, either by the wholesale dealers or hosiers, who pay after a certain rate for work performed; or by a class of middlemen, called master stocking-makers, who charge a certain sum for the use of their frames, without reference to the quantity of work performed. These frames are protected by law from distress for rent and from execution for debt; the master stocking-makers collect the work, pay the operatives, and transfer it to the wholesale dealers. In some instances, however, there is an approach to the factory system; when one master stocking-maker is the owner of several frames, which he collects under one roof, and engages operatives to work at them, paying for the amount of work produced.

The stocking-frame is a complicated machine, the number of moving parts being large, and collected together in a small compass. Nice workmanship is required in the construction of a frame, and any little derangement, such as the bending of a needle, is fatal to its action. The separate parts are made by the *frame-smith,* and are put together by the *setters-up,*

who are also frame-menders; but in ordinary cases, the stocking-maker keeps his own frame in working order.

In attempting to describe the stocking-frame, we must again refer to the process of hand-knitting, in which two straight wires, or *knitting-needles*, are used, and the operation consists in forming a series of loops upon one needle and inserting them within another series contained upon the other needle. This is effected by four movements :—1. By pushing the right-hand needle through the first loop of the left-hand needle. 2. By turning the thread once round the right-hand needle, to form a new loop. 3. By drawing the new loop through one of the former series. 4. By pushing the old loop off the left-hand needle. When one row of loops is completed the needles are made to change hands, and a new course is commenced.

In knitting by the stocking-frame a number of needles is employed, varying according to the fineness of the work, from 15 to 40 being contained in an inch; the largest number being used for the finest stockings. They are made of iron wire of the shape represented in Fig. 2352, with a hook or

Fig. 2352. NEEDLE OF THE ACTUAL SIZE.

barb at the end, and the sharp ends very fine and delicate. There is a small cavity or groove, shown in Fig. 2353, punched or sunk in the stem of each needle immediately beneath the barb, of sufficient depth to receive the point when pressure is applied upon the hook to bend the barb down. The barb then becomes a closed eye, and if a thread is looped over the stem of the needle and drawn forwards while the barb is thus closed, it will pass over the barb of the needle and come off at the end of it: but if the thread is drawn forwards while the barb is open, it will be caught under the hook, and thus be detained. The principal action of the machine depends upon this circumstance. The depression of the barbs of the needles is produced by the edge of a *presser-bar*, shown in end section, Fig. 2352, which is extended horizontally over the whole length of the needles, and is acted upon by pressing the foot upon the middle one of the three treadles of the machine.

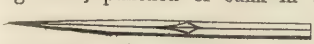


Fig. 2353.

The needles are fitted into the frame by being first cast into tin sockets, called *leads*. The form of the needle, when complete and fitted to its place in the frame, is shown in Fig. 2352. In front of the needle-bar is a small piece of iron, called the *verge*, to regulate the position of the needles. When placed upon the bar, resting against the verge, another plate of iron, generally lined with soft leather, is screwed down upon the sockets or leads, in order to keep them all fast. When the presser-bar is forced down upon the barb, the needle is shut, and when the presser-bar rises, the barb rises or opens by its own elasticity. Fig. 2354 represents a single thread formed into a number of loops by arranging it over an equal number of parallel needles; these are retained or kept

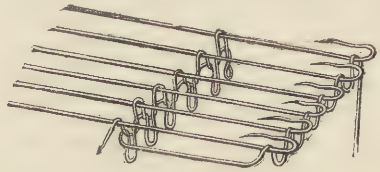


Fig. 2354.

in the form of loops by being drawn or looped through similar loops formed by the thread of the preceding course of the work. This is the common stocking-stitch used for plain hosiery; and the whole operation of the common stocking-frame consists in the formation of a series of loops, and then drawing them successively through a series of other loops, as long as the work is continued. There are many different kinds of stocking-stitch used for ornamental hosiery, each requiring a different frame or machine to produce it.

The next part of the machine requiring description is that for forming the loops. This consists of two parts, the *jack-sinkers* and the *lead-sinkers*. The jack-sinkers consist of a succession of horizontal levers or jacks, *j*, Fig. 2355, moving upon a common centre; each jack is furnished with a joint, from which hangs a very thin plate of polished iron called a *sinker*. One of these jacks and sinkers is allotted to every alternate needle in the frame, the sinkers hanging down between them. The other ends of the jacks are tapered to a point; and when the jacks are in their horizontal position, they are secured by small iron springs, s, each having a notch to receive the point of the jack.

The *lead-sinkers* resemble the jack-sinkers, but are differently attached; for while the jack-sinkers admit

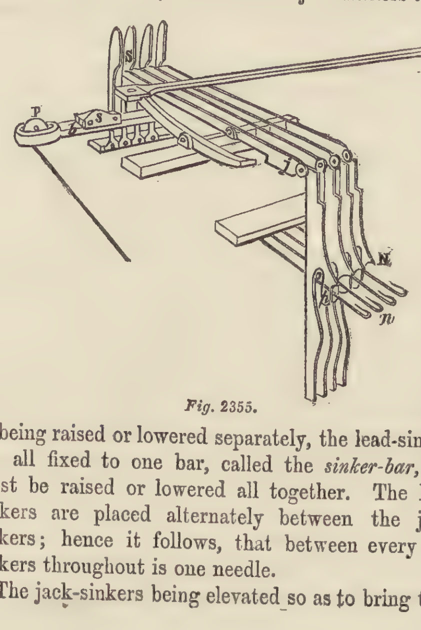


Fig. 2355.

of being raised or lowered separately, the lead-sinkers are all fixed to one bar, called the *sinker-bar*, and must be raised or lowered all together. The lead-sinkers are placed alternately between the jack-sinkers; hence it follows, that between every two sinkers throughout is one needle.

The jack-sinkers being elevated so as to bring their

nips, N, above the level of the needle, the thread is loosely thrown under these nips. Now, it is obvious that on lowering the jacks a series of loops will be formed; see Fig. 2354; but if the jacks were all lowered at once, there would be danger of destroying the thread, an accident which is avoided by a very ingenious contrivance. A straight iron bar, *b*, called the *slur-bar*, is extended beneath all the jacks, and upon this a piece of metal, *s*, called the *slur*, travels with rollers; motion is given to it by a cord attached to each side of it, passing over a pulley, *p*, and connected, by means of a wheel, with the two outer treadles of the frame. By this means, the slur is made to travel backwards and forwards, thus lowering only one jack-sinker at a time, and depressing one loop of thread between every pair of needles. The loops thus formed are of double the depth required; in order, therefore, to bring them to the proper size, and to throw a loop between every two needles in the frame, the workman next depresses the lead-sinkers all at once, and their nips, N, carry down the thread between the remaining needles in loops. While this is being done, the jack-sinkers are made to rise up as much as the lead-sinkers are depressed; thus making all the loops throughout of the same size, and forming a loop between every two needles. This row of loops is next driven back upon the needles, so as to come below the arch or opening of the sinkers, *a*, Fig. 2356. Here the loops are entirely removed from the action of the sinkers, and the workman proceeds to form a new row in front of the former, by a repetition of the process already described. The second row of loops is then brought forward, so as to be under the barbs or hooks of the needles. The presser-bar is next made to close the barbs with the thread within them. The first formed loops are now brought forward from under the arch, upon the closed needles, and are made to pass over the ends of the needles, and the new-formed loops within them. By this means the loops of what was the upper or last course of the finished work became secured, and the loops under the barbs now become the upper course, and are preserved from unravelling by the needles, one of which passes through each loop; and these loops will not be drawn off from the needles until there is another row of loops prepared and ready to be drawn through them.

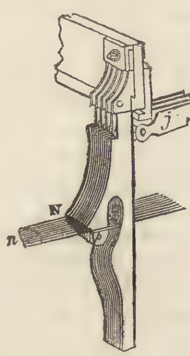


Fig. 2356.

This description of working the courses of loops within each other will perhaps be more intelligible if we follow the workman in another course. Preparatory to this, the loops of the last course, and by which the work is suspended from the needles, must be pushed back upon the stems of the needles, so as to come into the arched or open part of the sinkers, *a*; another row of loops is then formed and brought under the barbs; the barbs are then closed, and the row of loops under the arch is brought forward over the barbs, and over the ends of the needles, whereby the loops under the barbs are drawn through the loops which pass over the barbs, and thus, by a sort of circular motion, a web is formed which hangs down from the needles. When the piece is of considerable length, it is wound upon a roller contained in an iron frame, the weight of which is sufficient to keep the web properly stretched. Thus the various movements of the frame required in stocking weaving are as follows:—Supposing the workman has put the work back on the needles, preparatory to another course, the *first* movement is *the gathering of the thread.* The thread is lightly extended across the needles, beneath the nips N of the sinkers, and by pressing the slur-treadle the jack-sinkers are depressed, one by one, so as to form double loops; this is called "*drawing the jacks.*" The *second* movement is called *sinking.* The whole row of lead-sinkers is depressed, while the jack-sinkers rise, whereby the thread is carried down into a loop between every two needles. The *third* movement is to bring the thread under the barbs of the needles. The *fourth* movement is to bring the work forward from the stems of the needles towards the barbs. *Fifth*, closing the barbs by the pressure of the presser-bar, and drawing the loops last made through the finished loops of the work. The finished loops are drawn over the barbs, and quite off from the needles; this draws the finished loops over the loops last made, which remain in the barbs of the needles.

There are certain details respecting the stocking frame, which, for the sake of clearness, have been omitted in the foregoing description. A few of them may now be noticed. The bobbins which supply the workman with thread are, in the case of silk hose, contained in a small covered barrel at the side of the frame, having in it a small quantity of water, the evaporation of which keeps the thread sufficiently damp for working. It is drawn out as it is wanted, through a hole in the cover of the barrel. In cotton hose, the bobbin containing the thread is merely placed on an iron spindle, fixed in one of the upright beams of the frame. The jacks with their springs, and the slur-bar, are mounted upon a strong bar called the *camel*, which moves upon four wheels, forming a sort of carriage, capable of being pushed backwards and forwards through a small space. In bringing a row of loops forward, so as to be under the barbs or hooks, the carriage is simply drawn forward, which advances all the sinkers together, and their points *p*, Fig. 2356, push forwards the thread till it comes into the barbs, and these prevent it from coming off the needles. The jacks also admit of being depressed by the workman's hand, and they recover their position when relieved, by the action of a steel spring. In pushing the work back upon the stems of the needles so as to come into the arched or open part of the sinkers, the hosier depresses the sinkers low enough for their point *p* to enter between

the needles, and then by pushing the sinkers back, the thread is driven back with them.

The fineness of the work depends on the number of loops which the thread makes in any given length, and this will be equal to the number of needles and sinkers in the same space. The number of needles in an inch is called the gauge of the frame, and when once this is fixed, it can never be altered; hence the work which it produces will always be of the same degree of fineness, so that when a stocking-maker has once purchased his frame, he is always limited to the same kind of work; he may, however, make it a little more dense or more slight, by drawing the loops very close, or by allowing a greater quantity of thread, and making the loops longer. The length of the loops will depend upon the depth to which the nips of the sinkers descend between the needles, when they carry down the thread into loops. To regulate this depth, the falling bar, or that piece which sustains the leads containing the row of needles, is made to rise or fall a slight quantity, by means of two adjusting screws. When the piece of work is finished and taken off from the frame, the last made row of loops must be secured by running a thread through them, or by some other means, or they would escape by drawing through the preceding loops, and these in like manner would release the previous ones, until the whole became unravelled. The working of the frames is one of considerable toil, but does not for ordinary goods require much skill and training. The employment is said to be injurious to the sight.

Section VIII.—Statistics.

The statistics of the important objects of manufacture, noticed in the preceding sections, are of great interest, forming as they do some of the principal exponents of the industry of a great commercial nation. Limited space, however, will not allow us to do more than quote a few general results. In the year 1852, the total declared value of British cotton manufactures, including twist and yarn, amounted to 29,878,087*l.* Of this amount, the British East Indies receive to the value of 5,358,442*l.*; the British West Indies, 472,517*l.*; British North America, 469,854*l.*; Australia, 337,960*l.*; British South Africa, 273,977*l.*; United States, 2,681,025*l.*; the Hanseatic Towns, 2,874,106*l.*; Holland, 2,042,888*l.*; China, 1,905,321*l.*; Brazil, 1,891,865*l.*; Turkey, 1,779,693*l.*; Portugal, 635,879*l.*; Chili, 571,310*l.*; Naples, 544,702*l.*; Sumatra, Java, &c., 511,568*l.*; Russia, 195,150*l.*; France, 186,216*l.*

The following articles were exported in the years ending 5th January, 1852, 1853:—

	Declared value. 1852.	1853.
Cotton manufactures, exclusive of lace and patent net	£22,049,202	£21,704,184
Lace and patent net	558,350	580,106
Thread for sewing	454,347	506,716
Stockings	197,367	237,342
Other descriptions	195,544	272,930
Cotton yarn	6,634,026	6,655,344
Linen manufactures, exclusive of lace of thread	3,822,935	3 857,030
Lace of thread	5,602	4,060
Thread for sewing	258,856	338,821
Other descriptions	20,003	12,439
Linen yarn	951,426	1,144,521
Silk, stuffs, handkerchiefs, and ribbons	531,552	546,651
Silk stockings	26,307	25,162
Other descriptions	193,518	254,221
Silk mixed with other materials:—		
Stuffs, handkerchiefs and ribbons	347,874	289,484
Stockings	4,758	4,511
Other descriptions	26,389	36,682
Thrown silk	57,803	192,467
Silk twist and yarn	138,577	201,002
Woollen manufactures, by the piece	5,251,184	5,412,347
——— by the yard	2,822,961	3,014,705
Stockings	114,467	117,032
Other descriptions	188,571	181,561
Woollen yarn	1,484,544	1,419,933

WEDGE. See Statics and Dynamics.

WEFT. See Weaving.

WEIGHING-MACHINE. A machine constructed near a turnpike, for the purpose of ascertaining the weight of the loads on wagons and carts which pass along the road. In order to prevent the roads from being too much worn, a certain weight for each breadth of wheel has been fixed by Act of Parliament, and the weighing-machine is necessary in order to ascertain that this weight has not been exceeded. Weighing-machines have been so contrived, that the carriage may be lifted off the ground, and hooks attached to a large steelyard, of which the fulcrum is raised by a combination of tooth and pinion work, moved by a winch handle. That arrangement, however, is to be preferred, which allows the wagon or carriage to be drawn on a wooden platform which is even with the surface of the road, and which forms, as it were, the scale-pan of a peculiarly constructed balance. The platform is placed over a pit, and so arranged as to move freely up and down without touching its walls. It rests upon four levers, A B C D, Fig. 2357, converging towards the centre, and each moving on a fulcrum, A B C D, and fixed firmly in each

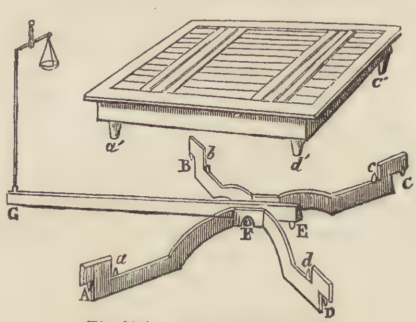


Fig. 2357. WEIGHING-MACHINE.

corner of the pit. The platform rests by its feet *a' c' d'*, upon steel points *a b c d*. The four levers are supported at the point F, under the centre of the platform, by a long lever G E, resting upon a steel fulcrum at F; its further end G being carried upwards into the turnpike-house, where it is connected with one arm of a balance; while a scale suspended from the other arm carries the counterpoise or *power*, the amount of which indicates the weight of the wagon

on the platform. As the four levers, A B C D, are equal and similar, the effect of the weight distributed among them is the same as if the whole weight rested upon any one of them; hence, to ascertain the conditions of equilibrium, we have only to consider one of these levers, such as A F. If the distance from A to F be ten times as great as that from A to *a*, a force of 1 pound at F would balance 10 at *a*, or on the platform. So also, if the distance from E to G be ten times greater than the distance from the fulcrum E to F, a force of 1 pound, applied so as to raise up the end of the lever G, would counterpoise a weight of 10 pounds on F; so that as we gain ten times the power by the first levers, and ten times more by the lever E G, a force of 1 pound tending to raise G, will evidently balance 100 pounds on the platform. If 10 pounds be placed in the scale-pan to which G is attached, it will express the value of 1,000 pounds on the platform. In this way, wagons and carriages can be weighed without difficulty. When the platform is not loaded, the levers are counterpoised by a weight applied to the end of the last lever.

The weighing-machine for goods in use at railway stations consists of a compound lever, or a composition of levers, as in Fig. 2358, which consists of three levers, two of the second kind, A F, A″ F″, and one of the first kind, A′ B′. The power P, acting upon the lever A F, produces a downward force, D, which bears to P the same proportion as A F to B F. If A P be 8 times B F, the force at B is 8 times the power P. The arm A′ F′ of the second lever is pulled down by a force equal to 8 times the power of P; and this will produce a force at B′ as many times greater than A′, as A′ E′ is greater than B′ F′. So that if A′ F′ be 10 times B′ F′, the force at B′, or at A″, will be 10 times that at A′ or B; but this last was 8 times the power, and, therefore, the force exerted at A″ will be 80 times the power. So, also, it may be proved that the weight W is as many times greater than the force at A″, as A″ F″ is greater than B″ F″. If A″ F″ be six times B″ F″, the weight W will be 6 times the force at A″. As this is 80 times the power P, the weight when in equilibrium will be 480 times the power. We may obtain the same result more expeditiously by dividing the product of A F, A′ F′, and A″ F″, by that of B F, B′ F′, and B″ F″. Thus, if the three former distances were 16 inches, 20 inches, and 18 inches; and the three latter, 2 inches, 2 inches, and 3 inches; then $16 \times 20 \times 18 \div 2 \times 2 \times 3 = 480$. The ratio of 480 : 1 is said to be compounded of the three ratios, 8 : 1, 10 : 1, and 6 : 1. Thus, it will be seen that when a system of this kind is in equilibrium, the ratio of the power to the load is compounded of the ratios subsisting between the arms of each lever; or, in other words, the power multiplied by the continued product of the alternate arms, commencing from the power, is equal to the weight multiplied by the continued product of the alternate arms, beginning from the weight. See BALANCE—STATICS AND DYNAMICS—ROADS AND RAILROADS.

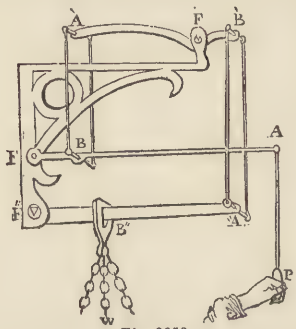


Fig. 2358.

WEIGHTS AND MEASURES. All the common books of arithmetic, and most almanacs and pocket-books, give useful tables of weights and measures, with which most readers are familiar. Instead of giving those tables in detail here, we shall offer a few explanations concerning the standards adopted; and as the French language is now more extensively known in England than that of any other foreign country, we shall present a few equivalents in English and French measures.

Until about thirty years ago, the standards of weight and measure in England were most irregular and unconnected. The standard of length was a metal *yard*, which had been in the custody of the Clerk of the House of Commons since the year 1760. In Scotland, the *Scots ell*, measuring 37½ English inches, was a standard whence the Scots *acre* was derived. The standards of weight were the *Troy pound* which had been constructed in 1758, and the *Avoirdupois pound*, the former of which bore to the latter the ratio of 5,760 grains to 7,000. The *Scots troy pound* differed both from the English troy and the avoirdupois; and, moreover, it differed in different parts of Scotland. The standard of liquid measure was the *gallon*, which was, however, of unequal size for ale, wine, and corn; and the *pints* and *firlots*, which formed the units of measure in Scotland, were equally irregular. The standard for dry goods was generally heaped measure, which varied of course according to the degree in which it was heaped.

Many of these inequalities were removed by an act of Parliament passed in 1824. The old yard is, by this enactment, retained as the standard of length; and in order to verify it in case of destruction, a ratio was established between its length and the length of a pendulum. It was found that a pendulum, vibrating seconds in the latitude of London, measures 39·1393 of such inches as are marked on this standard yard. The old troy pound and avoirdupois pound are also retained (having the ratio 5,760 to 7,000, or 144 to 175); and, in the event of the standard troy pound being destroyed, a ratio has been established between troy weight and the weight of a certain bulk of water. A cubic inch of distilled water, at a pressure of 30 inches, and a temperature of 62° F., is found to weigh 252·458 troy grains. The new standard measure of capacity is the *imperial gallon*, equal in bulk to 10 pounds avoirdupois weight of distilled water at 30 inches barometric pressure, and 62° F. This new gallon is larger than the old wine gallon and corn gallon, but a little smaller than the old ale gallon. The *peck*, *bushel*, and *quarter*, are all derived by multiples of this imperial gallon; and the *quart*, *pint*, and *gill*, by sub-multiples. For familiar purposes it may be useful to know, that a

vessel forming a $6\frac{1}{2}$ inch hollow cube would contain almost exactly an imperial gallon. Another act was passed in 1834, confirming and strengthening the provisions of the former act, and also prohibiting the further use of heaped measure; it also abolished (so far as an act of Parliament can abolish them) local and customary weights and measures throughout the kingdom, such as the *Winchester bushel*, the *Scots ell*, the *stone* (of any other weight than 14 lbs.), the *boll*, &c. At the time when the Houses of Parliament were destroyed by fire, the old standard troy pound was much injured, and the standard yard was altogether lost; measures have since been taken to reproduce equivalent standards, adhering to the actual values as established in 1825.

In France, the weights and measures have undergone a more marked change than in England. There was no relation between the *pied*, the unit of length, and the *livre*, the unit of weight; and weights and measures of the same name differed greatly in different parts of the country. In 1788, the government ordered a scientific inquiry to be made into the best mode of reforming the whole affair; but it was many years before the "new *metrical* system," as it is called, was completed and brought into public use; and even now, in country places, the old measures are still partially retained by those who are too ignorant or too prejudiced to appreciate the advantages of the new. This new system rests on a scientific basis. All weights and measures are derived from the *mètre*, which is equal to $\frac{1}{10,000,000}$th of a quadrant of the earth's circumference, from the pole to the equator. To this word *mètre* are prefixed the syllables, *deca*, *pecto*, *kylo*, and *myria*, to denote 10, 100, 1,000, and 10,000, respectively; or *deci*, *centi*, and *milli*, to denote $\frac{1}{10}$th, $\frac{1}{100}$th, $\frac{1}{1000}$th. This is *long measure;* and from it is derived *land measure*, by calling 100 square mètres an *are*. They obtain *dry* and *liquid measure* by making the unit or standard a *litre*, equal in capacity to a cubic decimètre; while, for *solid measure*, the standard is a *stère*, equal to a cubic mètre. Lastly, to complete the series, *weight* is allied to the mètre, by making the *kilogramme* to be equal to the weight of a cubic decimètre of water, at the temperature of 4° Fah. above melting ice. All these units, by the use of the prefixes, *deca*, *deci*, *hecto*, *milli*, &c., become applicable to any weights or any measures, large or small; and as the multiple 10 connects all the larger and smaller measures with the unit, the whole become easily susceptible of decimal computation. Notwithstanding the advantages of this complete system, however, the French government have found it expedient to permit the limited use of the older weights and measures; and thus we still frequently meet with *pieds*, *pouces*, *lignes*, *aunes*, *toises*, *lieues*, *arpents*, *cordes*, *vergées*, *boisseaux*, *pintes*, *tonneaux*, *livres*, *gros*, *grains*, *onces*, &c.

The following comparative statement of English and French measures will be found useful:—

MEASURES OF LENGTH.

ENGLISH.	FRENCH.
Inch, *Pouce*, ($\frac{1}{36}$th of a yard)	2·539954 centimètres.
Foot, *Pied*, ($\frac{1}{3}$d of a yard)	3·0479449 decimètres.
Yard, Imperial	0·91438348 mètre.
Fathom (2 yards)	1·82876696 mètre.
Pole or perch ($5\frac{1}{2}$ yards)	5·02911 mètres.
Furlong (220 yards)	201·16437 mètres.
Mile (1760 yards)	1609·3149 mètres.

FRENCH.	ENGLISH.
Millimètre	0·03937 inch.
Centimètre	0·393708 inch.
Decimètre	3·937079 inches.
Mètre	39·37079 inches. 3·2808992 feet. 1·093633 yard.
Myriamètre	6·2138 miles

SUPERFICIAL MEASURES.

ENGLISH.	FRENCH
Square yard	0·836097 square mètre.
Rod (square perch)	25·291939 square mètres.
Rood (1210 square yards)	10·116775 ares.
Acre (4840 square yards)	0·404671 hectare.

FRENCH.	ENGLISH.
Square mètre	1·196033 square yard.
Are	0·098845 rood.
Hectare	2·471143 acres.

MEASURES OF CAPACITY.

ENGLISH.	FRENCH.
Pint ($\frac{1}{8}$th of a gallon)	0·567932 litre.
Quart ($\frac{1}{4}$th of a gallon)	1·135864 litre.
Gallon, imperial	4·54345797 litres.
Peck (2 gallons)	9·0869159 litres.
Bushel (8 gallons)	36·347664 litres.
Sack (3 bushels)	1·09043 hectolitre.
Quarter (8 bushels)	2·907813 hectolitres.
Chaldron (12 sacks)	13·08516 hectolitres.

FRENCH.	ENGLISH.
Litre	1·760773 pint. 0·2200967 gallon.
Decalitre	2·2009668 gallons.
Hectolitre	22·009668 gallons.

WEIGHTS.

ENGLISH. (TROY.)	FRENCH.
Grain ($\frac{1}{24}$th of a pennyweight)	0·064798 gramme.
Pennyweight ($\frac{1}{20}$th of an ounce)	1·555160 gramme.
Ounce ($\frac{1}{12}$th of a pound troy)	31·103191 grammes.
Pound troy (5760 grains)	373·238296 grammes.

ENGLISH. (AVOIRDUPOIS.)	FRENCH.
Dram ($\frac{1}{16}$th of an ounce)	1·772 gramme.
Ounce ($\frac{1}{16}$th of a pound)	28·349 grammes
Pound avoirdupois	453·558 grammes.
Hundredweight *Quintal*, (112 pounds)	50·80 kilogrammes.
Ton (20 cwt.)	1016·04 kilogrammes

FRENCH.	ENGLISH.
Gramme	15·4325 grains troy. 0·6430 pennyweight.
Kilogramme	15432·5 grains troy. 2·6793 pounds troy. 2·2046 pounds avoirdupois.

In round numbers, for convenient calculation, where minute accuracy is not necessary, it may be well to bear in mind, that 1 cwt. is almost equal to 50 kilogrammes, and consequently 1 ton to about 1,000 kilogrammes.

WELD, a yellow dye stuff, consisting of the dried leaves and stem of the *Reseda luteola*, an annual herbaceous plant indigenous in Britain and other parts of Europe. It exists in the cultivated and wild state, and is gathered when in seed, its dyeing power being then greatest. The cultivated plant yields most dye. The decoction has a slight acid reaction, and a greenish colour, which is deepened by alkalis, and made paler

by dilute acids. It forms a yellow lake with alum, acetate of lead, or protochloride of tin. A white substance called *luteoline* may be obtained by treating the decoction with hydrated oxide of lead, decomposing the resulting compound with sulphuretted hydrogen, and evaporating the filtered liquor. Luteoline is a white volatile substance, subliming into yellow and white needles. *Luteoléine* is formed by the action of alkalies upon luteoline; it is a yellow crystalized sublimate, sparingly soluble in water, but freely so in alcohol and ether.

Saw-wort (*Seratula tinctoria*), and *dyers' broom* (*Genista tinctoria*), contain each a colouring principle similar to that of weld. See LACKER.

WELDING is the art of joining together two pieces of iron by means of heat. In technical language, this is called *shutting together*, or *shutting up*. The operation bears some resemblance to that method of forming joints described under CARPENTRY, called *scarfing;* but in smith's work the joints, also called *scarfs*, do not, from the adhesive nature of the iron when raised to the proper temperature, require anything answering to the glue, bolts, straps, and pins, used for joining wooden beams and girders. In joining two cylindrical ends, the scarfs required for the *shut* are made by upsetting or thickening the iron by hammering its extremities; it is then rudely tapered off to the form of a flight of steps, and the sides are slightly bevelled or pointed. The two extremities are next raised to the welding heat, when a little sand is sprinkled upon each; this fuses and spreads into a kind of varnish, which defends the hot metal from the oxidizing influence of the air. The proper heat has been attained when the iron begins to burn away with vivid sparks. Two men then take each one piece, strike them forcibly across the anvil to detach any loose cinders, then place them in their proper positions for the joint, when they are united by two or three blows of the fireman's hammer; and his assistant completes and finishes off the work with a sledge hammer. The end of the rod is next jumped upon the anvil and struck end-ways, to prove the soundness of the joint, or to enlarge the part, should it have become reduced in size by the welding.

Examples of welding are given under FORGING—CUTLERY—IRON—GUN-BARREL.

WELLS. The method of procuring water from wells was practised at an early period in man's history. The importance attached to wells of water is illustrated in numerous passages in the sacred record; but the wells of Syria seem to have consisted of mere excavations in the sides of rocks and hills where springs of water existed, and the water rose so near to the surface as to be in reach of a bucket attached to a short rope. In ancient Greece, this method was also adopted, and it was usual to finish the orifice of the well with a cylindrical curb of marble. The operation of boring for water is at least 4,000 years old, and was extensively practised in Syria, Egypt, and other countries. The method of boring for water is described under BORING. The hydrostatic conditions of springs, wells, and fountains, are noticed under ARTESIAN WELLS.

The art of well-making in Modern Europe was, previous to the comparatively recent introduction of Artesian wells, confined to the sinking of circular shafts (as described under TUNNEL) until land-springs were met with. The operation of *steining* or lining the excavation with brick or stone is not required when the shaft is sunk through chalk or rock. In some cases, where a loose soil overlies the chalk, steining is required until the hard rock is met with.

It was formerly the practice in this kind of brickwork to use wedges of slate, bond timber, and common mortar; but the timber was liable to decay, and the lime of the mortar (unless hydraulic mortar were used) was liable to dissolve out, even supposing it would set quickly, which was not the case, and render the water of the well hard. The use of Roman and other descriptions of cement has of late years greatly improved the operation of steining. Puddling behind the brickwork in passing through loose wet sand or loam is also superseded by the use of concrete. In passing through land-springs the brickwork must be executed in cement, or cylinders of iron must even be used instead of brickwork. In short, the various precautions required for sinking shafts as described under COAL—MINE, MINING—ROADS AND RAILROADS, and TUNNEL, may be required in sinking the shaft of a well.

The bricks used in steining should be hard, square, and well burnt; malm-paviors or the best stocks should be used. The bricks are usually built in under the executed part of the work, as described in TUNNEL, Fig. 2185. The steining is commonly executed partly in dry and partly in cemented work, the latter forming rings at intervals which vary with the nature of the ground; from 5 to 12 feet in London clay; but in some cases a considerable distance requires to be laid entirely in cement. The rings are commonly 3 courses thick and about 9 inches in height. The bricks are laid flat, as in Figs. 2359, 2360, the courses

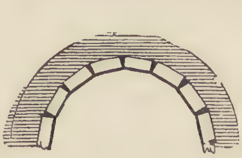


Fig. 2359.

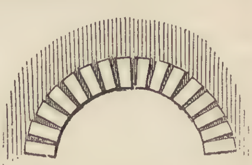


Fig. 2360.

alternately breaking joint; wedges or cement being introduced in the open spaces between the bricks. The thickness of the steining is regulated by the diameter of the well and the nature of the soil. In some cases 9-inch work is used, laid dry and radiating, as in Fig. 2360, or in separate 4½-inch rings, as in Fig. 2361. This of course is not so strong as four-and-a-half work, laid in cement. In excavating

Fig. 2361

from one ring to another, the hole is dug as far as the nature of the ground will allow, and a line is plumbed from the brickwork above, in order to determine the position of the face of the brickwork in the lower rim. In sandy soils, with a shallow well, the plan of working on a curb, described under TUNNEL, Fig. 2185, may be adopted, in which case the steining should be set entirely in cement.

As the work proceeds, the well-diggers become inconvenienced from the fouling of the air. Hence the excavation should be ventilated, for which purpose bellows or a fan-blast may be used to propel the air down zinc-pipes to the workmen. A plentiful supply of fresh air will enable them to perform their work with greater ease and expedition.[1]

WHALEBONE. This well-known substance is an albuminous tissue closely resembling hair and bristles in its chemical and vital properties and mode of development. It has nothing in it of the nature of bone, and hence the more appropriate term *baleen*, has been proposed for it. The whales or cetaceans, which produce it, are of a more timid nature than the great sperm whale; they have no teeth, but instead thereof, horny plates ending in a fringe of bristles. The largest of these plates are of an unequal triangular form, and are "arranged in a single longitudinal series on each side of the upper jaw, situated tolerably close to each other, depending vertically from the jaw with their flat surfaces looking backwards and forwards, and their unattached margins outwards and inwards, the direction of their interspaces being nearly transverse to the axis of the skull. The smaller subsidiary plates are arranged in oblique series, internal to the marginal ones. The base of each plate is hollow, and is fixed upon a pulp developed from a vascular gum which is attached to a broad and shallow depression, occupying the whole of the palatal surface of the maxillary and of the anterior part of the palatine bones. The base of each marginal plate is the smallest of the three sides of the triangle: it is unequally imbedded in a compact subelastic substance, which is so much deeper on the outer than it is on the inner side, as, in the new-born whale, to include more than one-half of the outer margin of the baleen-plate. The form of the baleen-clad roof of the mouth is that of a transverse arch or vault, against which the convex-dorsum of the thick and large tongue is applied when closed. Each plate sends off from its inner and oblique margin, the fringe of moderately stiff but flexible hairs which project into the mouth. The bases of the baleen-plates do not stand apart from one another, but the anterior and posterior walls of the pulp-fissure are respectively confluent with the contiguous divisions of the bases of the adjoining plates at their thin and extreme margins, which by this confluence close the basal end of the interspace of the baleen-plates, which interspace is occupied more than half-way down the plate by the cementing substance or gum. Thin layers of horn, in like manner, connect the contiguous plates, and may be traced extending in parallel curves with the basal connecting layer across the cementing substance. The baleen-pulp is situated in a cavity at the base of a plate like the pulp of a tooth; whilst the external cementing material maintains, both with respect to this pulp and the portion of the baleen-plate which it develops, the same relations as the dental capsule bears to the tooth. The baleen-plates are smallest at the two extremities of the series; in the southern whale (*Balæna Australis*), they rapidly increase in length to the 30th, then very gradually increase in length to about the 140th; from this they as gradually diminish to the 160th plate, and thence rapidly slope away to the same small size as that with which the series commenced. Besides the external plates just described, there are developed from the inner part of the palatal gum in the *Balæna Australis*, a series of smaller fringed processes progressively decreasing in size as they recede from the large external plates; the small plates clothe the middle region of the palate with a finer kind of hair, against which the surface of the tongue more immediately rests; they are also arranged in longitudinal series, which however are not parallel with the external one, but pass from the inner margin of that series in oblique lines inwards and backwards. In the great northern whale (*Balæna mysticetus*), the baleen plates, which succeed the large ones of the outer row, are more numerous, and are relatively longer and larger, than in the *Balæna Australis*. The marginal plates are about 200 in number on each side; the largest are from 10 to 14 feet, very rarely 15 feet in length, and about a foot in breadth at their base. Each plate of the baleen consists of a central coarse fibrous substance, and an exterior compact fibrous layer; but this reaches to a certain extent only, beyond which the central part projects in the form of the fringe of bristles. The chemical basis of baleen, according to Brande, is albumen hardened by a small proportion of phosphate of lime. The final purpose of this singular armature of the upper jaw of the great whales is to secure the capture and retention of the small floating mollusks and crustaceans, which serve principally as their food. When the capacious mouth is opened, the water rushes in, and is strained through the fringed surface of the roof and sides, whilst the small animals are retained, bruised against the stiff-bristled margins of the plates, and swallowed."[2]

Baleen or whalebone possesses some valuable properties, which cause it to be applied to a variety of useful purposes. It is prepared for use by being boiled in water for several hours, by which it becomes soft enough to be cut up while hot into the required lengths. By means of a compound guarded knife, it is cut into fibres as a substitute for bristles in common brushes. Whalebone that has been boiled is harder and of a deeper colour than before; jet-black whalebone is the result of dyeing. The chief consumption of whalebone is for the stretchers to

(1) In Mr. Weale's Rudimentary Series will be found an interesting treatise on Well-digging, Boring, &c., by Mr. Swindell, 2d edition, revised by Mr. Burnell, 1851.

(2) Professor Owen. Lecture at the Society of Arts, "On the Raw Materials from the Animal Kingdom displayed in the Great Exhibition."

umbrellas and parasols. It was formerly used largely in imparting stiffness to women's stays; the consumption for this purpose has considerably declined of late years, owing to a conviction that the artificial shape produced by tight lacing is not only injurious to health and personal comfort, but that the natural shape is more graceful to the eye. Whips are also made of plaited whalebone, both black and white. Ladies' bonnets and artificial flowers have been made of shavings of white whalebone, its texture being well adapted to the purpose; very bright and durable colours can also be imparted to it by the usual processes of dyeing. Solid pieces of whalebone of mixed shades are sometimes twisted together for walking-sticks; but this substance does not admit of being soldered like tortoise-shell. Whalebone is used for covering pocket-telescopes, and such covers are neat and durable. In such an application narrow pieces of whalebone are grooved or made into ribs by drawing them through an aperture in a steel plate, after which they are wound round the tube, and "tucked under" the rings at the extremities. Broad flat strips of party-coloured whalebone (the light portions of which have been dyed green, the darker portions rejecting the dye) are also used; they are secured by narrow black bands which overlap the two edges, the ends being also furnished with bands.

Whalebone is polished by first scraping it with steel scrapers or pieces of window-glass, next rubbing it with emery-paper, and then with woollen cloth supplied with tripoli or rotten-stone.

WHALE OIL. The Greenland whale (*Balæna mysticetus*) is valued for the sake of its oil. Its pursuit forms an important branch of industry as well as a nursery for British seamen. It was formerly found on the east shores of Greenland, but of late years in Davis's Straits and the interior of Baffin's Bay. The ships engaged in this trade are furnished chiefly by the ports of North Britain; Hull, Peterhead, Dundee, and Aberdeen, being the chief. The ships usually quit the Shetland Isles in April, and reach their locality in May or June. As soon as a "fish" is seen the boats are sent out in pursuit, and when near enough for the purpose, it is struck with a harpoon or barbed spear, to which a long line is attached. The whale dives and swims rapidly under water, his direction being indicated by the running out of the line. The boats follow in this direction, waiting until the animal comes up to the surface to breathe, when other harpoons are darted into its body, and the creature again dives. In this way its strength becomes exhausted, and being at length dispatched with long steel lances, it is towed alongside the ship, made fast with tackles, and the superficial blubber *flensed* off by men, who walk on the carcase with spiked shoes. When both sides of the animal have been stripped, the whalebone got out, and the jaw-bones, which are full of oil, hoisted on the deck to drain, the carcase or *kreng* is cut adrift. A large whale will often yield above 20 tons of rendered oil, which, with the other products, may be worth nearly 1,000*l*.

The Greenland whale rarely exceeds 70 feet in length; it was formerly of much larger size, and it is probable, from the eager pursuit of this animal, that it seldom attains the adult size in the northern seas. The head is about one-third of the whole length.

Common whale, or *train oil*, has a specific gravity of 0·927 at 68°. At 32° it deposits stearine; it is readily saponified, forming a brown soluble soap.

The *Cachalots*, or sperm whales, are remarkable for their enormous heads, which are square, and apparently cut off in front. The head is hollowed into large caverns containing a peculiar oil, which on cooling becomes hard, and when refined forms *spermaceti*. The animal is pursued chiefly for this substance, for it produces no whalebone and very little blubber. It also furnishes *ambergris*. The Phyceter, or sperm-whale, is of great size and strength, and becomes furious when wounded. It is pursued both in the northern and southern seas, and the pursuit is accompanied with great danger.

The oil of the spermaceti-whale is purer and burns more brilliantly in lamps than common whale-oil Its specific gravity is about 0·927, and it saponifies readily. Spermaceti may be purified by pressure, and by boiling in a weak solution of potash: it is next washed, melted in boiling water, and cast into blocks: when the exterior has become solid, the liquid interior portion is allowed to flow out, and the interior of the block then exhibits a beautiful lamellar crystalline texture. Spermaceti is greasy to the touch its sp. gr. is 0·94; it fuses at 112°. It is very sparingly soluble in hot alcohol: it dissolves in the hot oils. By trituration with alcohol, a little oily matter is extracted, and the residuary pure spermaceti has been named *cetine*. Its formula is $C_{208}H_{208}O_{16}$. It does not saponify readily with hydrated alkalies, but when digested with a solution of caustic potash, in twice its weight of water, for several days, at a temperature between 120° and 190°, it becomes converted into a peculiar soap containing margarate and oleate of potash, together with an unsaponified fat termed, by Chevreul, *ethal*, $C_{32}H_{33}O,HO$. Ethal is a neutral crystallizable fat, of which the melting point is nearly the same as that of spermaceti, but it is much more soluble in alcohol; it can also be sublimed without decomposition. According to one view, spermaceti contains neither oleic nor margaric acid, but the product of its saponification is said to be *ethalic acid;* hence spermaceti has been regarded as an *ethalate of ethal*. Ethalic acid resembles margaric acid in many respects. Spermaceti yields by oxidation with nitric acid a large quantity of *succenic acid*. See AMBER.

WHEAT. The composition of wheat is given under BREAD and STARCH. The former article also contains a description of the various processes for preparing flour by the common method. The results of the Great Exhibition have furnished various particulars respecting improved methods of cultivating wheat, and grinding it into flour, which we now proceed briefly to enumerate. Professor Lindley, in his Lecture delivered to the Society of Arts on the Vegetable Products of that great display, makes

certain statements respecting wheat which we here abridge.

Wheat will probably be regarded by many as all-important in the vegetable world, and there are some circumstances connected with it which particularly deserve to be brought under public consideration, and especially one which, although the corn-factors in Mark Lane are familiar with it, is by no means a matter of universal notoriety—viz. the high character and excellence of the wheat of our South Australian colonies. A sample of wheat from Adelaide, presented probably the most beautiful specimen of corn that has ever been brought to market in any country. It is a white wheat, in which every grain appears to be like every other grain—plump, clear-skinned, dry, and heavy, weighing, what may seem incredible to those who are only accustomed to common wheat, 70lbs. a bushel. And it appears that Adelaide is capable of yielding vast quantities of corn of this description, which takes the lead in the markets of this country over all other white wheats.

It is very true that from Spain there has come a similar kind of wheat, of great excellence also, as is seen by a beautiful sample from Castile, the weight of which is unknown, and not easy to estimate, because it is not a clean sample. This is certainly of great excellence also; but, independently of its being the produce of a foreign country, it is almost inaccessible to us, and therefore a matter of curiosity more than of practical value, because, owing to the difficulty of transport, it cannot at present come into the markets of this kingdom. If it could, considering that it sells in Old Castile at 24*s.* a quarter, it is not easy to say what might be the effect upon the English market of the introduction of any large quantity of it. We find moreover that similar qualities of wheat, growing in the same rich country of Spain, are vendible at much lower rates. With respect to the wheat of South Australia, it has been supposed that all we have to do in this country, in order to obtain on our English farms wheat of the same quality as this magnificent Australian corn, is to procure the seed and sow it here. There cannot be a greater mistake. The wheat of Australia is no peculiar kind of wheat; it has no peculiar constitutional characteristics by which it may be in any way distinguished from wheat cultivated in this country; it is not essentially different from the fine wheat which Prince Albert sent to the Exhibition, or from others which we grow or sell. Its quality is owing to local conditions—that is to say, to the peculiar temperature, the brilliant light, the soil, and those other circumstances which characterise the climate of South Australia in which it is produced; and, therefore, there would be no advantage gained by introducing this wheat for the purpose of sowing it here. Its value consists in what it is in South Australia, not in what it would become in England. In reality, the experiment of growing such corn has been tried by Dr. Lindley, and the result was a very inferior description of corn, by no means so good as the kinds generally cultivated with us, the crop therefrom being ugly, coarse, and bearded. It appears, therefore, that wheat may be affected by climate, independently of its constitutional peculiarities; but it does not follow that wheat is not subject to constitutional peculiarities like other plants. There are some kinds of wheat which, do what you may with them, will retain a certain quality, varying but slightly with the circumstances under which they are produced; as, for example, is proved by some samples, especially of *Revitt* wheat, of a very fine description, exhibited in the building by Mr. Payne, and which is greatly superior to the ordinary kinds of Revitt that appear at market. This clearly shows that Revitt wheat of a certain kind and quality is better than Revitt wheat of a different kind, both being produced in this country; so that, circumstances being equal, we have a different result, owing to some constitutional peculiarity of race.

But there is one question of the highest interest, which has been more distinctly brought out in the Great Exhibition than it has ever been before. We all know the effect of *hybridizing*, or crossing the races of animals; and we also know that, within certain limits, this may be done in the vegetable kingdom. We are all aware that our gardeners are skilful in preparing, by such means, those different varieties of beautiful flowers and admirable fruits which have become common in all the more civilized parts of Europe, but no one has paid much attention to the point as regards cereal crops. Yet it is to be supposed, that if you can double the size of a turnip, or if you can double the size of a rose, or produce a hardy race of any kind from one that is tender, or the reverse, in the case of ordinary plants, you should be able to produce the same effect when operating on cereal crops. It so happens, however, that the experiment has not been tried, except on the most limited scale, and to what extent it may be carried has been more brought out in this Exhibition than it ever was before. In the last treatise on this subject by Dr. Gaertner, a German writer, who has collected all the information it was possible to procure relating to the production of hybrids in the vegetable kingdom, the author declares that, as to experiments on cereal plants, they can hardly be said to have had any existence. The Exhibition has nevertheless shown us that they have been made, and proves distinctly that you may operate upon the constitutional peculiarities of wheat, just as you may upon the peculiarities in any other plant. For instance, Mr. Raynbird of Laverstoke, who obtained in 1848 a gold medal from the Highland Society for experiments of the kind, sent to the Exhibition a box, which contained a bunch of *Hopetoun wheat*, a white variety, and a bunch of *Piper's Thickset wheat*, which is red. The latter is coarse and short-strawed, and liable to mildew, but very productive. Mr. Raynbird desired to know what would be the result of crossing it with the Hopetoun wheat, and the result was shown in the form of four hybrids, obtained from these varieties. The new races thus obtained are intermediate between the two parents,—the ears are shorter than in the Hopetoun, and longer than in the Thickset wheat; in short, there

is an intermediate condition plainly perceptible in them throughout. And it appears from the statement of Mr. Raynbird that these hybrid wheats, which are now cultivated in this country, have succeeded to a satisfactory extent, yielding forty bushels an acre. But in this instance, as in some others, the essential part of the question is not the number of bushels produced per acre, but to show that you may affect the quality of cereal crops, as you may affect animals and other plants. Mr. Maund, an intelligent gentleman, residing at Bromsgrove in Warwickshire, has done much more than Mr. Raynbird, for he has obtained a greater variety of results. Mr. Maund has been occupied for some years past in the endeavour to ascertain whether something like an important result cannot be produced upon wheat by *muling*, and he exhibited the specimens before us in evidence of what may be done. You will observe that sometimes his hybrids are apparently very good, and sometimes worse than the parents, as we know is always the case. When you hybridize one plant with another, you cannot ascertain beforehand with certainty what the exact result will be, but you will take the chance of it, knowing very well that out of a number of plants thus obtained, some will be of an improved quality. In the present specimen, in each instance the male parent is on the left hand, the female on the right, and the third specimen shows the result of combining the two kinds: a better illustration could not be desired. Here is a hybrid considerably larger than the parents, and in the next instance one considerably shorter and stouter. In another example, you see a coarse variety gained between two apparently fine varieties—that is, perhaps, a case of deterioration. In another example, you have a vigorous wheat on the left, and a feeble one on the right, while one much more vigorous than either is the result. On the other hand, we have some anomalous cases, in which the effect of hybridizing has been to impair quality. This is a very important case, well made out, because the moment you show that by mixing corn, as you mix other things, you obtain corresponding results, there is no reason to doubt that an ingenious person, occupying himself with such matters, will arrive at the same improvements in regard to varieties of corn as have already been obtained in the animal kingdom, and in those parts of the vegetable kingdom which have been so dealt with.

We now proceed to state some of the improved processes of *milling* or *mealing* wheat; and having lately inspected the machinery and arrangements of a highly intelligent and enterprising miller, Mr. Feltham, of Crowborough in Sussex, we will briefly notice them, and also the arrangements of the City flour mills, which we have recently visited. The varieties of flour used in London consist chiefly of the following kinds:—1. *Best flour*, known as *Pastry Whites;* 2. *Whites;* 3. *Households;* 4. No. 2, or *Seconds;* 5. *Thirds;* 6. *Fine Middlings.* There is also a peculiar kind of flour used for *dusting*, in order to give a fine colour and texture to the outside of loaves. Any one of the above varieties of flour has distinctive properties of its own which are well known in the trade, and is produced by the admixture of several varieties of wheat, so proportioned as to secure the desired qualities of *whiteness, strength,* and *fermentability.* Thus, a wheat rich in gluten may be mingled with one which contains abundance of starch; a red wheat may be combined with one that is white; or a wheat that is moist with one that is dry. The art of mealing depends for its success upon the judicious mixtures of wheat, and upon such an arrangement of machinery that the whole of the flour which the wheat is capable of producing may be obtained from a single grinding. From the mixing bin the wheat is passed through a blowing apparatus, the object of which is to separate dust and light particles; it is then passed through a smut-machine, consisting of iron beaters, enclosed within a skeleton cylindrical frame covered with wire, (that of a square section being preferable,) with spaces sufficiently wide to allow the abraded particles to fall through. The beaters revolve from 400 to 500 times per minute, and by their action against the wires, scrub the wheat, and cause the particles of dust, &c. to fall through the wire covering to the outside. The wheat is next passed into a screen, arranged spirally on a horizontal axis, so as to expose a length of 30 yards. The revolutions of this screen further separate dust and small seeds. Finally, after leaving the screw, it is exposed to a current of air from a fan, which completes the removal of chaff, dirt, or shell of smut-ball. That this elaborate process of cleaning is not superfluous, is evident from the large accumulation of dust, dirt, and offensive matter, in and about each piece of cleaning apparatus. The result is that the flour is improved in whiteness and wholesomeness, and the reputation of the mill maintained for high qualities of flour. The various cleaning machines are so arranged that the wheat is passed from one to the other without loss of time, and it proceeds from the last blower to a hopper which supplies the mill-stones. The ordinary method of grinding is described under BREAD. Since that article was written, improved methods have been introduced, the objects of which are to prevent that loss of fine flour, arising from the centrifugal force of the runner, whereby the air of the mill is charged with fine particles, and the health of the millers injured. In Swayne and Bovill's improved method of grinding corn, the stones are completely boxed in, and a blast of air is so directed upon the grinding surfaces that the stones are kept cool, and the flour is removed as fast as it is formed. These gentlemen state truly, that in mills of common construction the flour is of necessity re-ground, or rather mashed up with the unreduced particles, until by the action of the running stone it is slowly discharged at the outer edge, considerable heat and colour having been thus imparted to it, and its strength materially impaired. They go on to state, that by their new process the flour is delivered from between the stones, at the instant of its production, in a cool state, leaving the surface of the stones free for the purpose of grinding only. By this process about 8 bushels of

wheat can be ground per hour, 4 bushels being the limit by the ordinary method. About 80 per cent. of fine flour is obtained, cool and fit for dressing as fast as it is ground, thus saving labour, space in the mill, and avoiding waste. The waste need not exceed 1½ per cent. or 6 lbs. to the quarter, since all the *stive* is caught and conveyed into a chamber, where it is collected and mixed in with the flour. By cooling the flour as fast as it is produced, it is not discoloured, so that a larger proportion of red wheat may be used in the mixing-bin, and as good a colour be obtained, as if the wheat had cost three or four shillings per quarter more. Another advantage of cooling is, that the meal can be dressed through silk machines (to be described); and thus a quality of flour can be obtained equal to that of France, where the superior dryness of climate allows of a more perfect dressing. It is stated that the bakers can make from 4 to 6 loaves more per sack from this flour than from that prepared by the ordinary process. By this plan the wheat does not require to be dried before grinding.

The arrangement of the apparatus will be understood by reference to Fig. 2362, which represents a

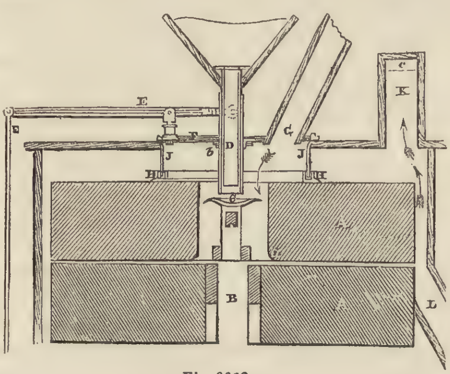


Fig. 2362.

vertical section of a pair of ordinary mill-stones,[1] with the patent apparatus attached. A A are the stones as usually employed, with furrows cut ⅜-inch deep, and the lower edge of the eye of the runner bevilled to freely admit the air-blast, as shown at *a*. B is the driving spindle, on which the cup C is attached, to receive and distribute the grain from the telescope feed-pipe, D, which is regulated in the ordinary manner with the lever and rod, E E. The centre of the stone case is closed by a cast-iron plate, F, having apertures for receiving the blast-pipe, G, and feeding-tube, D, a leather ring or washer being fixed at *b*, forming an air-tight joint through which the feeding-tube works. G is the air-pipe from an ordinary fan or other blowing-machine. H is a cast-iron grooved ring, attached to the top of the running-stone around the eye. J is a circular leather inserted into the groove of the cast-iron ring, and secured to the mill-stone case under the plate F, the object of which is to prevent the current of air or any grain passing otherwise than through the centre of the running-stone. The blast of air, blowing from the centre outwards between the grinding surfaces, discharges in its current, in a pure state, every particle of meal as soon as it is produced from the grains. In this process the furrows of the stones must be considerably enlarged. K is a waste air-pipe, 12 inches square and 3 feet high, having an elbow, *c*, on the top, the opening being in the contrary direction to the run of the stone. The escape-pipe for the air is placed over an opening of the same size, cut on the top of the stone case, which admits of the free egress of the wind blown through the stones without waste of meal. L is a meal-spout, 12 inches square, and not contracted at the bottom, by the arrangement of which and the waste-pipe, K, any stive or waste of meal is entirely avoided. For this purpose the blast of air, having served its purpose between the mill-stones, is conveyed into a room or closet lined with woollen cloth of peculiar texture, through which the air filters, leaving behind the fine particles of flour which would otherwise escape into the mill. An exhausting pipe containing a fan is connected with this closet, for the purpose of facilitating the escape of air. The only objection which we have heard to this otherwise excellent arrangement is, that the cloth soon becomes so choked with flour in a moist state as to arrest its action in filtering the air, and so to require frequent renewals of the cloth.

Another arrangement, known as the *Conical Flour Mill*, has of late years excited considerable attention, and led to much discussion. The principle of this invention may be given in the words of Mr. Boyman's statement, contained in the prospectus issued by the "Conical Flour Mill Company," which we here insert, with the omission of certain superfluous observations. The defects of the old system are thus stated:—

"For a pair of stones 4 feet diameter, an engine of 4-horse power, actual, is required. The lower stone is fixed; the upper one weighing 14 cwt. revolves, the grinding surface working at a mean velocity of 15·184 feet per second, when the stone makes 120 revolutions per minute, the average number for this power. Through a hole of 10 inches diameter, called the eye, in the middle of this revolving stone, the wheat enters, and is drawn between the stones and ground, the stones being slightly chiselled out in lines, called dressing, to produce the grinding surfaces.

"So heavy a weight, flying round at this high velocity, soon crushes the wheat, and reduces the contents to flour, when it ought immediately to escape, but cannot; so large is the area of the stones, so great is the pressure of the top stone, and so clogged up do they become by the sticky meal having to travel so far. Thus, from the instant that the meal is retained beyond the time required to grind it, deterioration commences, and power begins to be uselessly consumed in getting it out of the way, which it can only do very slowly; for every particle must describe a volute, with minute, but gradually enlarging circles, until it gets to the edge or skirt of the

(1) Messrs. Bovill and Swayne have introduced a new description of Burr stone from Belgium, which is said to be equal to the best French mill-stones.

stone, and is discharged. And were the co-efficient of friction resistance to the centrifugal velocity ascertained, the actual distance to which the meal is subject to this grinding action could be determined. But it must be very great, circling as it does round a stone of 4 feet diameter, since the friction resistance of an adhesive substance like meal to the centrifugal action is so considerable. It is thus easy to see that some portion of the bread-making properties of the flour are destroyed by so much unnecessary trituration, and that much power is consumed in getting rid of a material so retarding as meal, beyond that required merely to grind the wheat.

"The Conical Mill obviates these defects to as great an extent as is practicable, because it is the nearest approach to natural mechanics. We can see with what admirable economy of power the jaws of the horse are contrived to grind his corn. The heavy, head-bearing, upper jaw is fixed; the lower one moves, and being of little weight, requires but little power to move it. It is also an upward pressure, so that no weight rests upon the corn, as in the present erroneous system. Its pressure, therefore, is exactly proportioned to the work it has to do, and no more; whilst the lower grinders, with their serrated edges, may be likened to little mill-stones of small surface, which, with a semi-rotary motion, reduce the corn to meal. Designedly or not, the Conical Mill is on precisely the same principles throughout. The upper stone is fixed, the lower one revolves, and instead of being 14 cwt., like the upper revolving stone of the present mills, is only 1 cwt. 2 qrs. Thus the upward pressure is as nicely proportioned as the horse's jaw, sufficient only to open, not to crush, the corn. It is, too, of small surface, like the grinders of the horse, and set at an angle not many degrees removed from that of the horse's jaws.

"These natural principles of grinding, Mr. Westrup has very ingeniously carried out. Instead of having one small conical surface, whereby some of the meal would be re-ground, and the stones become clogged, though not to the same extent as on the old principle, he divides even this smaller surface into two, by having two pairs of conical stones on the same shaft, the lower pair about 2 feet 3 inches beneath the upper, so that each surface is only as 1 to 3·34 of the old. And to prevent any portion being re-ground, the first object to be avoided in good milling, there are vertical brushes fixed to the shaft, between the two pairs of stones, extending to a radius of 14 or 15 inches, and nearly touching a fine-meshed cylinder that surrounds the whole mill. No sooner, then, is the fine flour liberated from the upper stones, than it is sent through the cylinder by these revolving brushes, whilst all that will not go through has not been sufficiently ground, and so passes down into the second pair of stones, which complete the process."

It is asserted that this is the true principle of grinding; "the means of getting what it has been the great object of the best millers to get—as much of the very best and whitest flour possible at the first grinding, and to get it as soon as possible; that is, the moment the wheat has been opened and the farina liberated, which is done soon after the wheat enters the eye. But, as we have seen, this object never can be accomplished whilst the flour has to travel round and round a 4-feet stone. Every miller, then, will see what a superior flour must be obtained from a stone whose grinding surface is only 3·5986 feet, and which delivers its flour at a mean velocity of 21·8333 feet per second, as compared to that which has to pass over a grinding surface of 12·021 feet, and which is only delivered at a mean velocity of 15·184 feet per second. The smallest possible surface, the quickest possible delivery consistent with coolness, and the greatest possible quantity, ground at the first casting, and with the smallest power, constitute the great principles of milling, and here they are all combined.

"It is gratifying to find that all the results of the French practice are now reached in this country, so far as regards the quality of the flour obtained from the first casting or grinding; whilst it is greatly surpassed as regards the quantity ground by a given power in a given time, and also in the money value of the total produce from a given quantity of wheat, the first cost of the wheat being the same. Thus the Conical Mill will do all it is possible for the best French mill to do, and a great deal the best French mill cannot do. It will give quantity as well as quality. The French mill will only give quality. The French miller takes care to give his mills only the exact quantity they can grind, that the first operation may be well done; and this quantity is about one-half less than even the common English mills, of the same sized stones, grind in the same time; and only by this slow process can the French millers get that fine white flour, so pleasing to the eye in the best Paris bread, called '*Farine de Gruaux*.' But this tedious grinding would not do in England, where time, the measure of labour, is money. It will not do for a people who, of all the peopled earth, know best how to do the most work in the least time, and who live, for all practical purposes, measured by the useful work done, twice as long as any other race. And what they do themselves they make their machines do. With us every invention is a mere pounds, shillings, and pence affair. What will it do? and what does it cost in doing it? So that quantity is as essential as quality. Thus the inventor of the Conical Mill does precisely what the French miller does, only by a better, because more time-saving, economical system. As a practical miller, he knew the importance of preventing re-grinding; but, instead of reducing the quantity of wheat to prevent it, he reduces the surface of the stones, removes all injurious pressure, gives them a different shape, and a higher velocity; and thus he gets as good a flour as the French miller, whilst he grinds three or four times as much in the same time, and, by the Engineer's Report, nearly twice as much as the ordinary English mills. Such then is the difference between the two systems of milling, from which it will be seen that we still preserve our twenty years' advance of our neighbours in this art, as we believe we do in most of the great

substantialities of life that make up the solid greatness and prosperity of a nation.

"As regards the ability to grind nearly double the quantity of wheat with the same power, the solution will be found in the area of each grinding conical surface being as only 1 to 3·34 of the horizontal stone, a reduction that can only be obtained by the peculiar form of the stones. The result of an area so much smaller is, as before alluded to, a very remarkable saving in power, arising from the great decrease of the resistance of so adhesive a substance as meal over so large an area as the old stone, between such rough and close surfaces, and beneath so heavy a pressure. Were the co-efficients of this resistance known, a theoretical investigation might be given of the saving of power; but without such data the mathematician will best understand how impossible it is to go into this question.

"By analogy, however, some idea may be formed of how great this loss must be, from the fact, that the friction of water through a pipe only six times as long as it is wide, consumes $\left(\cdot 01482 + \frac{\cdot 017963}{\sqrt{v}} \right) \frac{l}{d} \cdot \frac{v^2}{2g}$ = 11·4 per cent. (Weisbach, vol. i. sec. 330 and 331.) And were the pipe made of wood, the co-efficient of resistance would be 1·75 times more than for smooth metallic pipes, whence we see how much greater still the loss must be with a sticky material like meal, and passing through rough stones, where, probably, the loss would be, not merely as $\frac{l}{d}$, but as $\frac{l^2}{d}$, or $\left(\frac{l}{d}\right)^2$; because its particles do not momentarily communicate equal pressure in all directions, like water, and so get out of the way by an equal pressure throughout its mass; for the further the meal has to be forced between such very rough surfaces, (so closely pressed too as not to exceed the thickness of ordinary writing paper,) the more compressed and unyielding must it become; therefore the greater must be the resistance to motion, increasing (doubtless) at least as the square of the distance, and requiring proportional power to get rid of it. When therefore the surface passed over is reduced in the proportion of 1 to 3 34, it is easy to perceive how great the saving must be; because the meal being got rid of with the new stones as soon as it is ground, and the space between the stones being wider, that power, which, with the old stones, is consumed in forcing it from between the stones, and in re-grinding it, goes to grind the fresh wheat."

The conical flour-mill does not appear to have come into very general use, although it may possess many advantages over the common arrangement of stones. One objection urged against its use is the liability of the lower or running stone to fall away from the upper stone, when by any diminution of the power, either by a deficiency in the supply of water or of steam, there is a consequent diminution of centrifugal force. In the common arrangement of stones, if the power be not properly kept up the stone will *pitch*, that is, get nearer to the bed-stone, so that should the engine-man be negligent there is not an absolute loss of profit, that is, the corn may be over ground and the quality injured, but the quantity will be rather increased. In the conical arrangement, should the stone fall away from its work, the grain would not be ground sufficiently fine, and some of the best part of the wheat would get into the middlings, and this would require the middlings to be ground over again. We are also informed that it is difficult to keep the conical stones *in floor*, that is, to dress their surfaces so that they may be always true.

The *gruaux* principle of grinding wheat, referred to above, is thus noticed in the Jury Report of the Great Exhibition, Class II.:—

"The magnificent gruaux wheat-flour of M. D'Arblay, jun. has occupied much of the attention of the Jury, not only as the best sample of European flour, but from the exhibitor being the inventor of the gruaux principle in grinding, whereby a great saving of the finest and most nutritive portion of the flour is effected, and any wheat-flour made to contain more or less gluten in proportion to starch. Hard wheats of all kinds, especially *Sicilian, Russian* and *Sardinian*, from the large per centage of gluten they contain, are the best adapted for this purpose. By means of D'Arblay's adjusting process, such grains are first ground high in the mill; the white middlings are then separated by coarse sieves, and re-ground low in the mill; finally, the flour is repeatedly passed through fine silk sieves. This process is evidently tedious and expensive; but the flour produced is of the very finest description, especially for *pâtes*, and other preparations of that description. The average produce of flour thus obtained is 25 per cent. from ordinary wheat. Such flour is extensively imported into this country, for bettering the inferior flours, especially the Irish. D'Arblay's *household flour*, obtained by the usual grinding process, is also of first-rate quality. A council medal has been awarded to M. D'Arblay 'for his gruaux and household flour, obtained by a novel and economical process, for the fineness of its quality and utility.'"

In the common arrangement of stones the meal passes down a shoot into a meal-bin. The falling meal conveys a considerable sensation of warmth to a hand held in it; and it is necessary to preserve the meal in sacks for some weeks, in order that it may *cool*, as it is technically called, or become fit for dressing. If the meal is thus treated, the flour made from it will stand its weight for months, but if dressed as soon as ground, the flour loses in weight about 4 lbs. per sack, and is also liable to *heat* and *cake*. The *dressing machine* [see BREAD, Fig. 226] is a skeleton cylinder covered with wire, and containing from six to eight brushes. The wire should vary in fineness from 54 to 72 meshes to the inch according to the weather, (the damper the weather, the coarser the wire.) This machine separates the meal into flour and middlings. The flour is a finished product; but the middlings require to be passed through a *bolting mill*, whereby three qualities are produced, viz. fine middlings, coarse middlings, and thirds flour. The

first of these is largely employed for sailors' biscuits, the second for pig-feeding, &c., the third is sold as thirds flour. Seconds flour is produced from an inferior wheat. The *refuse* or *offal* is passed through a *jumper*, consisting of a frame containing wire-gauze of various degrees of fineness, and is thus separated into four descriptions, viz. *superfine pollard*, *fine pollard*, *horse pollard*, and *bran*.

The most extensive and probably the best appointed flour mill in the world, is that erected within the last few years in Upper Thames Street, London, and known as the City Flour Mills. The mill, which is fire-proof, is 260 feet in length, and 60 feet in width. There are 32 pairs of stones all furnished with the patent blowing apparatus, the runner of each pair being worked by a strap. A long horizontal trunk placed above the mill-stones is supplied with condensed air by means of a powerful fan. From this trunk proceeds a smaller trunk obliquely into the casing of each pair of mill-stones, and when the blast has served its purpose, it escapes up another oblique trunk, into a second long horizontal shaft, in which the air is rarified by means of a fan. This trunk conveys the air into a chamber, lined with woollen cloth, as already noticed.

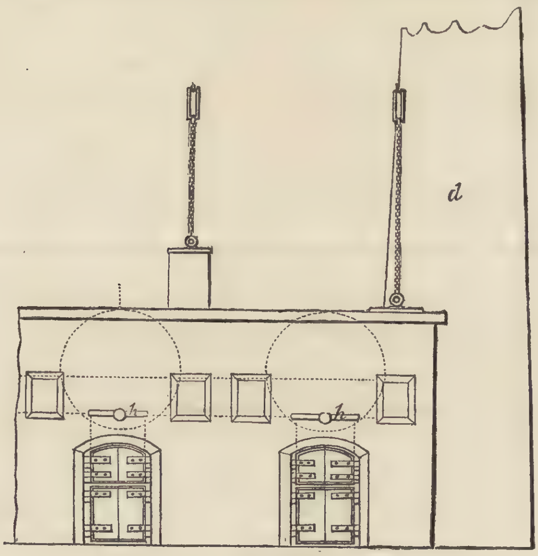


Fig. 2363.

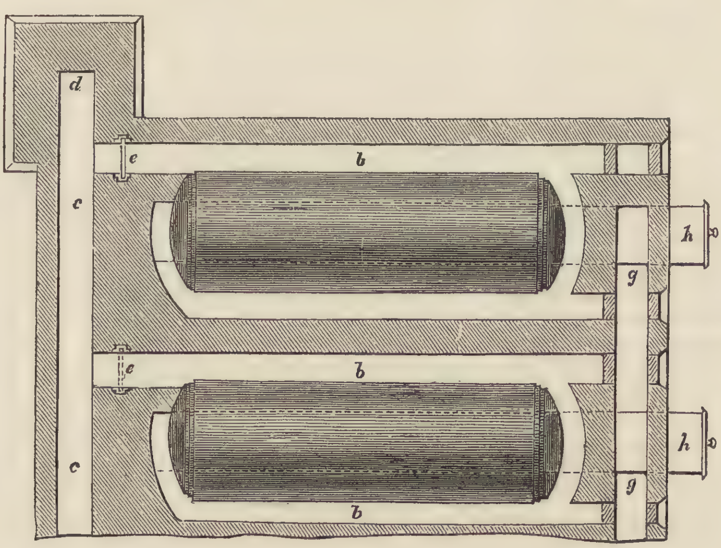


Fig. 2364.

The wheat is hoisted to the top floor, where, after undergoing certain cleaning operations, it is let down to the stones. The meal is conveyed along horizontal trunks, by means of Archimedean screws, working in them, to a series of elevators or buckets attached to an endless-band working in a vertical plane over and under rollers at the top and bottom. These elevators distribute the meal among sixteen silk dressing machines, each of which is 36 feet long, and 3½ feet in diameter, and inclosed within a casing of wood. The silk machine consists of an octagonal frame-work of wood, moving on a central axis, to which it is attached by means of light bars. The spaces of the framing are covered with a fine carefully woven silk of hard texture, stretched tightly. The axis is inclined three quarters of an inch to each foot of the length: the two ends of the machine are left open, and the meal being poured in at the upper end, as the machine revolves on its axis, each of the eight sides is made in turn to act as a sieve. But as this rotatory motion alone would not be sufficient to separate the fine flour, in consequence of the pores of the silk becoming stopped up, a vibratory motion is imparted to each surface of silk at the moment when it comes into action. For this purpose the light rods, which connect the frame-work with the axis, have wooden balls or stout rings of wood threaded loosely upon them, so that as the axis revolves, these wooden balls fall from the axis upon the framing, and from the framing back again to the axis: it is in falling upon the framing that the vibratory motion is imparted to the silk. The fine flour which passes through the machine proceeds down a shoot to appropriate receptacles, and is a finished product. The pollard, bran, &c., which do not pass through, fall out at the lower extremity of the silk machine, and are conveyed to suitable dressing-frames.

The average quantity of wheat ground per week at these mills is 2,500 quarters. The great advantage of working with the patent-blast and with the silk machines, appears from the fact that, by this method,

wheat can be ground and dressed within the short space of 15 minutes, during which time it passes three times from the top to the bottom of the mill by means of screws and elevators. Another advantage of these arrangements is the comparatively clear atmosphere of the mill, in consequence of the dust of flour not being allowed to escape. Only a small number of hands is required, most of the work of the mill being performed by steam-driven machinery. The steam-engine in this establishment is on the marine principle, and was formerly used as one of the stationary engines of the Blackwall Railway, when the carriages on that line were moved by means of a rope. The nominal power of the engine is 220 horse. There are seven boilers for generating steam, and the furnaces are made to consume their own smoke by the simple but ingenious and highly effective plan of causing one fire, as soon as it is supplied with coals, to discharge its smoke into the next adjoining fire. The arrangements by which this method is carried out, will be understood by referring to the accompanying figures. Fig. 2363 is a front elevation of a range of fireplaces furnished with Messrs. Bristow and Attwood's smoke consuming apparatus. Fig. 2364 is as ectional plan of the same. Fig. 2365 is a sectional elevation lengthwise of the boilers; and Fig. 2366 is a sectional elevation taken across the fireplaces. *a a* are the fireplaces, *b b* the flues leading therefrom into *c*, a flue common to all the fireplaces, and leading to the chimney *d*. When coals are about to be added to the fire, the opening into the chimney is closed by means of one of the dampers *e e*, and a damper *h* is opened in a flue *g g* which extends from end to end of the furnace, and affords a channel for the passage of the smoke from any one fireplace to any other in the range. The plan can be adapted to boilers at small cost, and is equally applicable to marine boilers. The following comparative trial made on the 22d March, 1854, at the City Flour Mills, will show the advantage of this apparatus :—

WITHOUT THE APPLICATION OF THE SMOKE CONSUMER.

	£	s.	d.
The quantity of coals consumed was 62 tons in 72 hours, or 1,928 lbs. per hour, consisting of 42 tons of Welsh, at 26*s*. per ton.....	54	12	0
And 20 tons of small, at 17*s*. per ton............	17	0	0
	£71	12	0

Total cost of coal per hour, 19*s*. 11*d*.

The engines were driving at this time 26 pair of stones, silk machines, and smutting machines.

WITH THE SMOKE CONSUMING APPARATUS APPLIED.

	£	s.	d.
The coals consumed were 49 tons in 57 hours, or 1,925 lbs. per hour, consisting of all small coals, at 17*s*. per ton	41	13	0
Or a cost of.......................................	14*s*. 7¼*d*. per hour.		
Thus a saving is effected, by being enabled to burn all small coals with the smoke consumer applied, of......	5	3¾	ditto
	19	11	

Or 36*l*. 13*s*. 1½*d*. per week of 138 hours.

Engines driving same machinery as above.

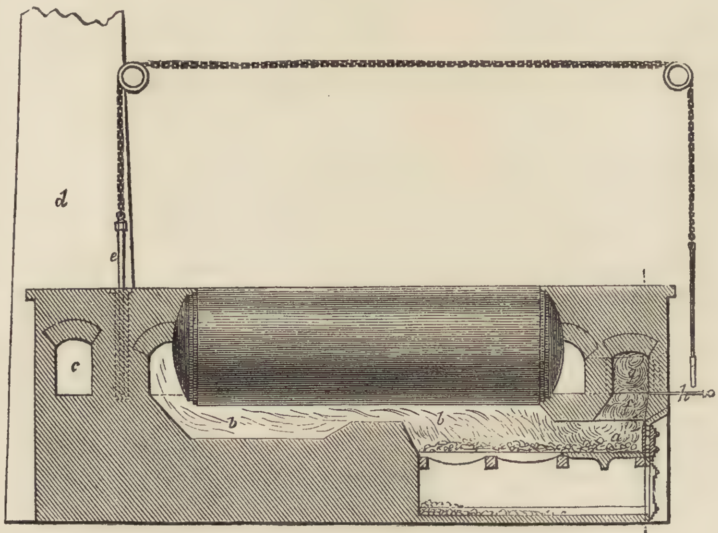


Fig 2365.

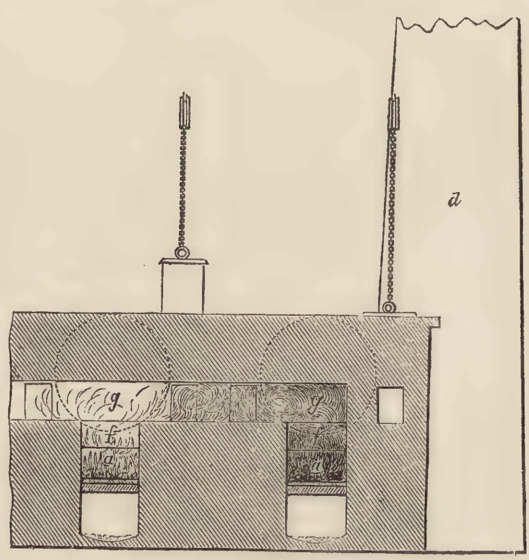


Fig. 2366.

The reason of the 20 tons of small coals being used in the above trial, was in consequence of having two of Juckes's patent furnaces at work, which have since been taken out.

WHEEL AND AXLE. See Statics and Dynamics.

WHEEL CARRIAGES. The cars, carts, chariots, vans, wagons, cabs, omnibuses, coaches, and other

vehicles which come under the designation of wheel carriages, necessarily bear a resemblance in respect to the principle of traction, however they may differ in form and adornment. The sledge, the palanquin, the litter, are examples of vehicles without wheels; but of those which come more within the scope of this article, we may say a little concerning carts and wagons on the one hand, and pleasure carriages on the other.

Modern improvements have rendered agricultural carts and wagons far superior to those made 20 or even 10 years ago. Mr. Pusey, in his Report of the Exhibition Jury on Agricultural Implements, stated that this improvement is very decided, and that a single-horse cart will now render as much farm-service in a day as a 2-horse wagon rendered a few years ago. The chief source of improvement consists in the substitution of iron for much of the wood-work, whereby a diminished weight and an increased capacity are insured. This is also the case in another class of merchandise-vehicles, the wagons and trucks used on railways; the framework of these vehicles, especially those on the broad-gauge made at Swindon, are constructed mainly, or indeed almost wholly, of iron.

Pleasure-carriages are constructed with so much care in England, that they have long been superior to those made in any other country. Their varieties are numerous; comprising landaus, coaches, chariots, berlins, broughams, landaulets, britzschkas, barouches, barouchets, phaetons, cabriolets, tilburys, curricles, tandems, stanhopes, dennets, gigs, chaises, &c. The points in which these differ are, that some are for 1 horse and others for 2; that some have 2 horses a-breast, and others 2 horses in file; that some have 2 wheels and others 4; that some are open and others closed. Mr. Adams, in his "Treatise on Pleasure Carriages," describes a system of "equirotal carriages," which he has introduced: the system depends upon a new adjustment of the under-framing of 4-wheeled carriages, whereby all the wheels are of the same size, thereby diminishing friction and inequality of motion: by a peculiar arrangement of the pole or perch, the carriage can turn without the necessity of the front wheels passing under the body of the vehicle. Although there is much ingenuity in this invention, the equirotal carriages have not come very extensively into use. The day of first-class stage-coaches is past in England, and we can scarcely look for any decided improvement in this class of vehicle. Omnibuses, though strongly made, are deficient in comfort and ventilation; it was expected that the numerous omnibuses and models of omnibuses displayed at the Great Exhibition would have led to improvements in the general construction of those used in London; but such improvements are not yet very apparent.

The coach-making art is one of the most elaborate carried on in London. In no other are the materials more carefully selected, or the processes more carefully carried on; and the workmen are in general very highly paid. The wood employed is various in kind. *Ash* is used for the skeleton frame-work of a coach; *beech* is employed in inferior carriages; *elm* is used for strong planking, and for wheel-naves; *oak* is used for the spokes of wheels; *mahogany* is used for panels or broad plain surfaces; *cedar* is sometimes used as a substitute for mahogany; *deal* and *pine* are employed in the flooring and roofing; *fustic, lancewood, birch, sycamore, chestnut,* and *plane-wood,* are all occasionally used in coach-making. The wood-work of the "body" is made by a wholly distinct set of workmen from that of the "under-carriage;" body-making more resembles cabinet-work, while carriage-making involves the stronger processes of carpentry. The iron work, and the works in the several metals, all call for much care in their execution. But perhaps the most remarkable operation in coach-building is connected with leather-work. In common carriages the wood is simply painted and varnished; but in carriages of a higher class the upper part is covered with leather, previous to painting. This leather covers the roof, and also the upper half of the front, back, and sides; yet it is all in one piece. A hide of leather, of large size and of perfect quality, is selected; it is thoroughly softened in water, and is thrown over the top of the coach, the edges hanging down on every side. The currier or workman begins by rubbing the leather down on the roof until it remains flat in every part; he curries all the four sides in succession, until a similar evenness is attained there also. But during this process, as will be evident from a little consideration, there will be folds or wrinkles at the four corners; and the strange part of the operation is, that by working the leather gradually from these corners to the centre of the sides and back, the wrinkles become rubbed out altogether, and the edges made as straight, and even, and tight, as any other part. This effect is due to the singularly pliant and yielding state of the moistened leather.

The paint on a well-made coach is of considerable substance. From 10 to 15 distinct coats are laid on the principal parts, each one dried and rubbed down before the next is applied; and 6 or 8 coatings of copal varnish prepare the surfaces for that beautiful polish which is, perhaps, more durable and perfect than in any other kind of wood-work.

WHEELS, TEETH OF. When two wheels act, the one upon the other, by means of teeth, it is a problem of much importance so to shape the teeth that no motion shall be lost by undue friction between the surfaces which come in contact. The teeth should be formed in such a manner that those of one wheel press in a direction perpendicular to the radius of the other wheel; that is, the pressure should be tangential to the wheel, as in the dotted line to the right of fig. 2367, or tangential to the pinion, as in the dotted line to the left.

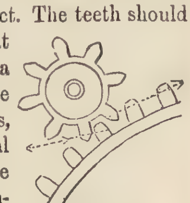


Fig. 2367

All arrangements of toothed wheels come under what is termed the "communication of motion by rolling contact." There are many designations of toothed wheels, according to

the mode in which the teeth are arranged. An ordinary *toothed wheel* has the teeth cast or cut in the wheel itself, forming one whole. A *cog* or *cogged wheel* has cogs of iron or wood, not formed with the wheel, but inserted in its edge, or on its face. A *spur-wheel* has the cogs or teeth on the edge or periphery, projecting radially from the centre. A *face-wheel* has the cogs or teeth at the periphery, but parallel to the axis of the wheel. A *bevelled* or *mitre-wheel* has the teeth formed upon a conical surface, the angle of the cone depending on the angle which the axes of the two wheels make with each other. When two toothed wheels of unequal size work together, the larger is generally called a *wheel*, and the smaller a *pinion*. If the pinion is formed of a number of raised rods placed between two circular ends, it is called a *trundle* or *lantern*. There are a few other technical terms which must be understood, in order to render intelligible the reasoning respecting the teeth of wheels. The wheel which imparts motion to the other is the *driver;* that which receives the motion is the *follower*. If, when the two are in contact, a straight line be drawn from centre to centre, that line is called the *line of the centres;* and if circles be described from these centres, with radii in the same ratio as the number of teeth in the two wheels, those circles are *pitch-circles*. The measurement of one complete tooth and its adjoining space constitutes the *pitch* of the wheel. For example, in fig. 2368, which represents a portion of the circumference of a pair of mill-wheels in gear, *m a n* is the pitch-circle of the upper wheel, and *e a c* the pitch-circle of the lower wheel. The forms of the teeth are those usually adopted in practice. The distance *a c* constitutes the pitch, being one tooth and one space; and the other dimensions are found in certain conventional ratios to this pitch. Thus *d e*, the depth to the pitch-circle, is $= \frac{3}{10}$ pitch; *d f* the working depth $= \frac{6}{10}$ pitch; *d g* the whole depth $= \frac{7}{10}$ pitch; *a b* thickness or width of tooth $= \frac{5}{11}$ pitch; *b c* breadth of space $= \frac{6}{11}$ pitch.

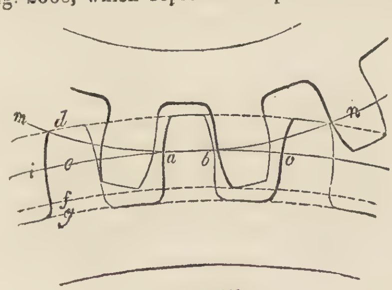


Fig. 2368.

In common mill-work, the sides of the teeth are generally made arcs of circles, the friction or rubbing being lessened by increasing the number, and consequently decreasing the size of the teeth. For some purposes the *epicycloid* (or curve described by a point in the circumference of a small circle rolling round the rim of the wheel) has been proposed; and for others, that the side of each tooth should be an *involute* from the pitch-line, that is, that it should be described by a pencil confined by a thread that is unwound from that line. When the teeth are numerous this curve will approach to a circular arc. There are frequently practical difficulties in giving to the sides of the teeth the epicycloidal curve. Equalization of motion is sometimes ensured in toothed wheel-work by having two or more rows of teeth on the same surface, succeeding each other uniformly, so as to ensure the continuous action of several teeth.

To form a wheel, the pitch circle A B *a b* is first drawn of the working diameter required for the wheel. This circle forms the working circumference of the wheel; for if two cylinders, equal in circumference to the pitch circles of two wheels, be made to act together by rolling contact, they would act similarly to two toothed wheels, for we may consider the teeth merely as enlargements of the roughnesses of the wheels which act by friction or rolling contact; for in such wheels, the working effect is promoted by the roughnesses of one surface falling into corresponding cavities on the other. In laying down, therefore, on paper, two wheels which are to act together, their pitch circles are described so as to be in contact, as at A B, *a b*, Fig. 2369. They are next divided into as many parts as there are teeth in the wheels, each part being made equal to a tooth and a space, or to the distance between the centres of two adjoining teeth, as at P P′. This distance P P′ forms the *pitch* of the wheel; C *c* the *line of centres;* R *r* the *pitch radii;* and R′ *r*′ the *real radii* of the wheel. The pitch of the wheel must not be too small, or the teeth will not be strong enough to work. A series of pitches is generally used for cast-iron wheels; those for the larger wheels being 1, 1¼, 1½, 2, 2½, 3 inches, and for small wheels, ¾, ⅝, ½, ⅜, ¼, inch.

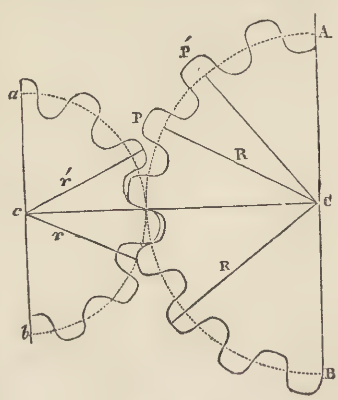


Fig. 2369.

To find the number of teeth in a wheel of given diameter and pitch, or to find the pitch or the diameter when the number of teeth is given, is not difficult. The circumference of a circle being equal to the diameter × 3·1416, and the pitch being equal to a tooth and a space, we thus get $\frac{\text{diameter} \times 3{\cdot}1416}{\text{number of teeth}}$, from which the other quantities may be found; for example:—

$$\text{No. of teeth} = \frac{\text{diameter} \times 3{\cdot}1416}{\text{Pitch}}.$$

$$\text{Diameter of wheel} = \frac{\text{Pitch} \times \text{No. of teeth}}{3{\cdot}1416}$$

If, for example, it were required to make a wheel two feet in diameter with 100 teeth, the pitch would be very nearly $\frac{3}{4}$ of an inch; for $\frac{24 \times 3{\cdot}1416}{100} = {\cdot}754$ in. If the pitch in the same wheel were required to be of one inch, the number of teeth in such case would be 75; for $\frac{24 \times 3{\cdot}1416}{1} = 75$. If the teeth were required to be of such a size that the pitch should be $\frac{1}{2}$ inch, and the number of teeth 120, the diameter of the wheel would be then only 19 inches; for $\frac{{\cdot}5 \times 120}{3{\cdot}1416} = 19$ inches.

A quicker method of finding the pitch is by dividing the diameter of the pitch circle into as many parts as there are teeth. This diametral pitch is some fraction of an inch, and the denominator of this fraction will be an integral number. Thus a wheel 10 inches in diameter with 60 teeth, will have a diametral pitch of $\frac{10}{60}$ or $\frac{1}{6}$. The most useful values of this denominator, which may be called P, are 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 20. A wheel, in which the denominator of the diametral pitch is 6, is called a *six-pitch wheel.* The circular pitch (which is obtained by multiplying the diametral pitch by 3·1416) corresponding with the above measures of the diametral pitch are as follows:—

Value of P.	*Circular Pitch.*
3	1 inch.
4	$\frac{3}{4}$,,
5	$\frac{5}{8}$,,
6	$\frac{1}{2}$,,
7	$\frac{7}{16}$,,
8	$\frac{3}{8}$,,
9	,,
10	$\frac{5}{16}$,,
12	$\frac{1}{4}$,,
14	,,
16	$\frac{3}{16}$,,
20	$\frac{1}{8}$,,

The rules for forming the teeth of wheels vary greatly; for some millwrights seek to obtain the highest degree of accuracy; while others attach more value to any method which is moderately accurate and easy of fulfilment. The teeth ought, in any case, to be so adjusted, that before one tooth has quitted its corresponding space, the next in succession will have entered the next space; and so on continuously; consequently the surfaces cannot escape from each other. Professor Willis, in his "Elements of Mechanism," gives one particular solution, applicable to trunnions or pin-wheels; in which he shows that an epicycloid traced on the pitch-circle of the driver by a describing circle equal to the pitch circle of the follower, will drive a pin in the circumference of the follower with the same motion as if the pitch-circles rolled together. A second solution is given, applicable to the metal toothed wheels now so largely employed. A third solution affords the means of determining the shape of the teeth in a wheel which shall be able to act on another having any greater or lesser number of teeth, provided that in both wheels the teeth have the same pitch. A fourth solution relates to involute teeth, which differ from epicycloidal teeth in this,—that whereas in an epicycloidal tooth the side is made up of two different curves, joined at the pitch-circle, in an involute tooth the entire side is formed of a continuous curve.

Workmen frequently adopt the following plan of determining the form of the teeth of wheels. They prepare *templets,* that is, a pair of boards whose edges are cut to the curvature of the pitch-circle and the describing-circle respectively. The describing templet carries a point in its circumference; and by rolling its edge upon that of the pitch-templet, the arc required for the face of the tooth is traced upon the drawing-board. This done, the workman finds with his compasses, by trial, a centre and small radius, by which an arc of a circle can be described, that will coincide as nearly as may be with the templet-traced epicycloid. Then, having struck upon the fronts of the rough cogs a circle concentric with the pitch-circle, and whose distance from it is equal to that of the centre of this small arc, he adjusts his compasses to the small radius, and always keeping one point in the circle just described, he steps with the other to each cog in succession, they having been previously divided into equal parts corresponding to the given pitch and breadth of the teeth. Lastly, upon each cog he describes two arcs, one to the right and one to the left, which serve him as guides in shaping and finishing the acting faces.

Mr. Willis characterises this method as one possessing great practical convenience, and requiring only a more commodious and certain method of determining the centre and radius of the approximate arc. He thereupon sought to remedy this defect, and to establish a working method which shall be easy of use, and yet approach very nearly to mathematical accuracy. He has invented for this purpose a small instrument called an *Odontograph,* or tooth-describer. It is a sheet of cardboard, about a foot long, by 8 or 9 inches wide. Along the edge of one side is a series of graduations, extending from 0 to 200, in a "scale of centres for the flanks of teeth," and from 0 to 40 is a "scale of centres for faces of teeth." There are also two printed tables on the card, to show the place of the centres upon the scales. The tables include any number of teeth from 13 to 150, and any pitch from 1 inch to 3 inches; one table gives the centres for the flanks of teeth, and the other for the faces.

In the works of Camus, Tredgold, Buchanan, Willis, Barlow, and other writers on the principles of mechanism, the mathematical principles on which the form of the teeth of wheels is determined, are fully considered. We refer to those works for a full exposition of the subject.

On the subject of the teeth of wheels for clocks, we have received the following communication from Mr. Denison:—

"In setting out large clocks there are two points which deserve attention. Both of them occur in the great Westminster clock, which Mr. Dent is making from my designs, and subject to the approval of the Astronomer Royal and myself on behalf of the Government.

"(1.) The first case is that of the great wheel of the going part having to drive a lantern pinion of 12, and also the hour wheel of 48 teeth. The lantern pinion of course fixes the shape of the great wheel teeth absolutely, and therefore those of the hour wheel must be accommodated to that shape, and cannot be radial teeth as usual. For this purpose, the flanks of the hour wheel teeth are traced by rolling on the inside of its pitch circle a circle of the size of the lantern pinion with a tracing point in its circumference. It makes the teeth an odd looking shape, much thicker than usual at the bottom; but the running is perfect. This wheel being driven, with the action entirely after the line of centres, no points, or projections of the teeth beyond the pitch circle are required. If it had had only 24 teeth they would have been of the common form, since the same teeth will drive a lantern pinion of *n* pins, and a common pinion of 2 *n* teeth or leaves. And on the other hand, if this pinion of 12 had not been made a lantern pinion, the teeth of the hour wheel would have had to deviate still farther from the common form.

"(2.) The other point is the form of the cams to raise the hammer levers; and this is the more important because the rule given for it in Camus (which seems to be the standard book with workmen) is wrong, as I have noticed in my Rudimentary Treatise on Clocks published in Weale's Series, p. 215. I have now got (from the suggestion of a friend) a more simple rule for tracing the cams than the one I have there given; it is this.—Let A B, Fig. 2370, be one division of the circle on which the cams are to be

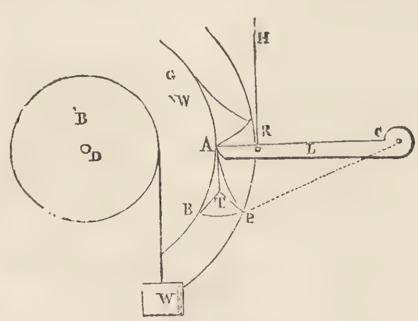


Fig. 2370.

traced; through A and B draw tangents, intersecting at T: T B will be the radius of a circle B P, which is to be the face of the cam. It is evident, that the lever C A will always be a tangent and never scrape on this cam, and also, that at the point P, where it drops off, it will be a tangent *at its end*, and therefore, the point of the cam will not scrape on the lever. The velocity of raising is not quite uniform, but that is of no consequence, for the reason mentioned in my book. This plan also has the advantage that only the length and not the curvature of the cam depends on the length of the lever, and therefore the same pattern of cam will do for levers of various lengths.

"You will easily conceive that every bit of friction is of consequence in this great clock, when I tell you that the pressure on the hour striking cams will probably be not less than 8 cwt."

WHET SLATE. See HONE.

WHEY. See MILK.

WHISKEY. See DISTILLATION.

WHISTLE, STEAM. See STEAM-ENGINE.

WHITE-LEAD. See LEAD.

WHITING is prepared by grinding chalk under a runner, then washing it in order to remove sand and other impurities, and lastly drying it in lumps. The particles of chalk in this state are so soft as not to abrade materials of tolerable hardness, and hence whiting is used as a finish in polishing metals, but its use for this purpose seems to be chiefly in absorbing the grease left in the previous processes.

WICK. See CANDLE—LAMP.

WINCING MACHINE. See CALICO PRINTING. Fig. 415.

WINDLASS. See CAPSTAN. In small vessels, the capstan is worked with the barrel in a horizontal position, in which case it is called a *windlass*. The power is applied by means of levers, which are worked in holes similar to those in the capstan-head.

WINDMILL. The principal parts of a windmill consist of an axle, A, A, Fig. 2371, inclined to the horizon from 8 to 15°, and 4 wooden sail-frames, V, V, each

Fig. 2371. SECTION OF COMMON WINDMILL.

about 40 feet long, attached at right angles to the upper extremity of the axis. Each sail-frame or *whip*, as it is called, consists of a long bar of wood with short pieces projecting therefrom at right angles, the outer extremities of these short pieces being connected together by a vertical lath of wood; on these frames sail-cloth is spread, so as to form a continuous surface capable of arresting the air in its motion and receiving therefrom the amount of pressure required for the revolution of the 4 arms: each sail begins at

about $6\frac{1}{2}$ feet from the axle A, and terminates at the extremity of the arm which supports it. The arms taper off towards the extremities. The frame-work which supports the mill turns round on a fixed vertical axle P, and a lever L is used for turning the frame-work so as to direct the axle A towards the wind. In some cases the roof only of the mill is movable; it is then circular in form, and revolves upon rollers, *r r*, Fig. 2372. This kind of mill is usually of stone in the form of a round turret, with a large wooden ring on the top. To produce the motion in the roof, the wooden ring on the top of the building is furnished with a groove, containing a number of brass truckles at certain distances apart, upon which, and within the groove, is placed another ring, on which the whole roof is supported. Beams are connected with the movable ring, and to one of them is fastened a rope, and attached to a windlass at the lower extremity, the rope is drawn through an iron hoop fixed at the ground, and the windlass being turned round the sails and roof will be turned round also. One objection to this construction is that the roof is liable to be blown off in a very high wind. As these methods of adjusting the windshaft must be put in operation by hand, a contrivance has been made for setting the sails by the action of the wind only. For this purpose a large wooden vane or weathercock V, Fig. 2372, is fixed to the extremity of a long

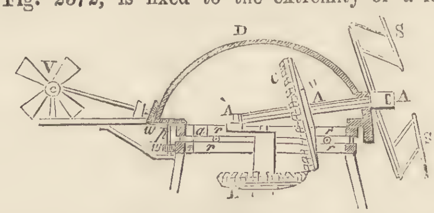


Fig. 2372.

horizontal arm lying in the same vertical plane with the windshaft, by which means when the surface of the vane and its distance from the axis of motion are of sufficient magnitude, a gentle wind will act upon the vane, so as to move the sails S S, and windshaft to their proper position. This plan may be adopted whether the mill have a movable roof or revolve on a vertical shaft.

The axis A, A′ makes an angle of from 10 to 15° with the horizon, because it has been observed that the direction of the wind is not generally horizontal, but describes a small angle with the surface of the earth. So also the surfaces of the sails are not placed in a plane perpendicular to the axis A, A′, but are slightly inclined therefrom, so as to receive the action of the wind somewhat obliquely. The sails are in fact arranged in such a way, that the pressure which each one undergoes shall tend to turn the axis A, A′ in one direction. But the obliquity of the surface of the sails with respect to the direction of the axis A, A′ varies somewhat in the length of each sail, diminishing from the axis to the further extremity of the sail. In well-constructed mills that part of the sail nearest the axis makes an angle of 60° with the direction of this axis, while the other extremity of the sail makes an angle of 80° therewith. This change of obliquity is required to meet the varying velocity of the sails at different points of their revolution. "According to Monge and Hachette each sail may be regarded as an irregular surface engendered by the motion of a right line perpendicular to the piece which sustains the sail, and which at the commencement of the sail, viz. nearest the turning axle, would form with it an angle of 60° on the windward side of this right line, passing over the whole length of the piece sustaining the sail, and remaining always perpendicular to it, but uniformly increasing the angle which it forms with the turning axle in such a manner that, at the extremity of the sail, the angle, which was 60° at the commencement, would become 78° if the axle A were inclined 8° with the horizon, or 84° if the inclination were 15°, and in proportion for intermediate inclinations. The position of the generating line serves to fix the direction of the cross pieces; together they form a frame which receives the sail-cloth: each sail may also be regarded as an irregular surface produced by the motion of a right line perpendicular to the piece sustaining the sail, and subject to touch in all its positions the right line drawn through the corresponding extremities of the position which the generating line should have at the two extremities of the sail as previously stated." It has been estimated by Coulomb that the total effect of a mill of this description working throughout the year 8 hours a-day is equal to the raising of a weight of 1,000 lbs. 218 feet per minute, an effect equal to the daily work of 61 men. According to Euler, the mill is acting with greatest efficiency when the velocity of the extremity of the sail is to that of the wind as 2 : 1.

When the wind is blowing strongly, it may be necessary to check the rapidity of motion in the arms, otherwise the moving parts might take fire by the friction: for this purpose, some of the canvas is taken in, by means of a rope properly adjusted, and which also serves for spreading out the canvas when it is required to expose a larger resisting surface to the wind. In either case, the adjustment requires the stoppage of the mill. Accordingly plans have been devised for rolling and unrolling the sails while in motion; but these plans do not seem to have come into general use.

When it is required to stop the mill, a break or gripe may be applied to the crown-wheel W, or the sails may be drawn down from the ends of the frames towards the axis A, and when it is required to set the mill in action, a man ascends each arm in succession, dragging the sail after him, and he adjusts it while a man below holds the opposite arm. In this operation the sails should be turned away from the wind. On the continent sails have been contrived on the principle of louvre boards, which are made to open and shut by means of racked bars attached to the axis.

The windmill is chiefly used in this country as a power for turning a millstone in grinding corn; for which purpose, a crown-wheel C, Fig. 2372, is attached to the axis, and the teeth of this wheel engage with those of another wheel L, attached to the ver-

tical axis of the millstone M. On the continent, the windmill is used as a power for driving saw-mills, oil-mills, for working the pumps used in draining, and for other purposes.

In situations where the great height required for the vertical sails would be an objection, the *horizontal windmill* may be used, although it is stated that such a mill has not much more than 1-fourth of the force of a vertical mill. A horizontal windmill consists of a wheel or *fly* formed by 6 sailbeams fixed to a central axis, as shown in Fig. 2373; to these beams are attached vanes placed so that their surfaces may be divided into two unequal parts by the axis of rotation. It must be evident, that however the vanes are arranged, while some of them are receding from the wind and causing the vertical axis to rotate, other vanes, in coming up to the wind, must produce so much friction or resistance as greatly to diminish the effect. Mr. Beatson attempted to overcome this difficulty by so arranging the vanes that the whole force of the wind might act in a direct manner on the resisting side, but when acting on the other or returning side, the parts of the vanes should give way and allow the wind to pass through. For this purpose the vane frames were filled up or covered with canvas or other light material in such a way as to form small separate parts or flaps, placed so as to overlap each other a little; by which means the flaps would be close shut when the wind was acting directly upon them, and the vane would receive its whole impulse just as if it consisted of one entire piece. But when a vane comes up to the wind the spaces are all open, the wind blows through, and the vane offers but little resistance. A better plan is to enclose the fly in a fixed cylinder, or screen formed by a number of louvre boards, arranged so that in whatever direction the wind may blow it may enter between them on one side only of a vertical plane, passing through the axis of the fly. In this way the wind acts upon the oblique surfaces of the boards on one side only of the axis, while the screen prevents the wind from acting upon those vanes which are coming round in the opposite direction.

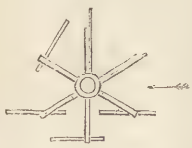


Fig. 2373.

WINE. The fermented juice of the grape. At a very early period in the history of the world, wine was produced by fermenting the juice of the grape, as is proved by the frequent notice of it in the most ancient writings. In many respects, however, the wines of the ancients differed from those of the moderns. They frequently had the consistence of liqueurs, and were impregnated with highly odorous and sapid substances; but they all contained alcohol, and had exhilarating or intoxicating qualities.

The wines of modern times are exceedingly numerous. Some chemists apply the term wine to every saccharine solution the sugar of which has been wholly or partially changed into alcohol. This is not generally done, although we are accustomed to apply the term wine to other fermented juices than those of the grape, and to distinguish them therefrom by naming the sources whence they are derived. Thus we speak of *ginger-wine*, *gooseberry-wine*, *currant-wine*, &c. The juices of various plants contain certain fermented saccharine fluids; thus the beetroot and the parsnip yield a fermentable juice; as do also the stems of the birch and cocoa palm; the spatha of the *Sagus vinifera* and other palms, the leaves of the vine and various kinds of fruit, such as gooseberries, currants, &c. The conditions under which a saccharine solution by the addition of a ferment, such as yeast, changes its sugar into alcohol, have already been treated of under FERMENTATION—BEER—ACETIC ACID—SUGAR—STARCH—GUM. By the more or less perfect conversion of the sugar of the vegetable juices during fermentation into alcohol, this substance is always present in wines, yet other substances are also present, the number and relative proportion of which, and the mode in which they are blended together, give to wines their distinctive qualities.

In the present article we shall confine our attention to the juice of the grape, which is by far the most important in wine making. The *Vitis vinifera* has a very considerable geographical range, extending from nearly 55° N. lat. to 45° S. lat. The grapes grown within this wide range are not all adapted to the making of wine. In Königsberg the grape only ripens in warm summers, and is deficient in sugar, while in southern regions the sugar is so abundant as to crystalize in the grape, while those acids are absent which are necessary to the flavour of the wine. Where much sugar is present, other conditions being favourable, rich sweet wines, known as *vins de liqueurs*, are prepared, such as Frontignac, Lunel, and Rivesaltes, prepared in the south of France from the Muscat grape, which on the Rhine furnishes a grape fit only for dessert. The local conditions which influence the quality of the grape are numerous, and often perplexing. The same latitude does not always allow the growth of a good wine-making grape: the position of the isothermal lines, the degree of moisture, the clearness or cloudiness of the atmosphere, appear to be of even greater importance than the composition of the soil: indeed it appears from recent observations that the ripening of fruits depends more on the illuminating rays than on the heating or chemical rays. The different climates in which the grape ripens impart to it certain distinctive characters: the grapes which are grown along the Maine or the Rhine, and which yield *Hock*, furnish *Bucellas* when grown near Lisbon, and *Cape Hock*, when grown at the Cape of Good Hope, a very different wine from the Rhenish. When grown at Madeira, the same sort of grape yields the *Sercial*, which differs from all the preceding. The composition and qualities of the soil have also some influence: when the soil is dark in colour, such as that formed by argillaceous schist, it radiates heat by night as well as by day, and the grape ripens easily. According to Chaptal it is of most consequence that the soil be porous, free, and light; its component parts being of secondary importance. Calcareous soils are said to be the best, because they readily imbibe

the rain, and allow a clear atmosphere to surround the vines. When differences occur in the quality of the same grape in the same district, and even in the same vineyard, slight variations in locality must be assigned as the cause. When the vine is planted on the side of a hill or mountain, the wine yielded by the grapes from the higher part of the slope will differ essentially from that afforded by the grapes of the lower part; thus the *Johannisberger* and the *Rüdisheimer* are the produce of contiguous vines which resemble each other in external characters. Johannisberg is only 150 feet above the level of the Rhine, and yet the produce of the summit near the castle is of a very superior quality to that produced in the Johannisbergerhöle or hollow; because in the former case a large and wealthy proprietor can command the best treatment for his vineyard, while the latter, being much subdivided, is cultivated with less skill. Moreover, the upper vineyard is surrounded with a stone wall ten feet high, which, by sheltering the grapes and securing a quiet state of the air, allows them to attain maturity under more favourable circumstances. This sheltering of the grapes is so evident in its effects in the Rheingau, that belts of vineyards which clothe the height of Hochheim, produce different wines according to their position. One morgen or acre close to the bed of the Maine, fetches 2,C00 florins in the market, a higher morgen 1,000 florins, and one at the summit only 500.

Wines of high reputation, however, owe their character to other circumstances, such as the variety of the grape and its mode of culture, selecting the most favourable time for the vintage, gathering and pressing the grapes with such rapidity that the contents of each vat may be in the same state, so as to secure a simultaneous and equal fermentation throughout; exercising judgment and care in the time and mode of drawing off the wine, and in its subsequent treatment in the casks where it is kept, and not selling the wine until it has acquired perfection, and only selling such vintages as are calculated to maintain the celebrity of the vineyard. In this way a few large proprietors have obtained for their wines a celebrity which is usually ascribed to locality or to something peculiar in the soil.

There are cases, however, in which a wine may become tainted through the presence of certain substances in the soil. Thus *stinkstone,* a native subcarbonate of lime, will give a repulsive taste to wine, which however comes to be relished in time, and hence the taint is not eradicated. In France and Portugal a strong opinion is maintained that manure deteriorates the flavour of the wine. The German cultivators, on the contrary, manure freely, not only with fresh cow-dung, but also with fragments of woollen cloth steeped in liquid manure and dried, and the produce is greatly increased thereby. This is not done very frequently, but at intervals of three or four years for red grapes, and of nine or ten years for white grapes. A valuable manure for vines consists of the cuttings of the vines themselves when pruned at the end of July or beginning of August: the fresh and moist prunings should be cut into small pieces and mixed with the earth, when they undergo putrefaction so completely as to disappear at the end of four weeks. They restore to the soil a portion of the alkalies abstracted by the grapes.

Vintages vary in character from year to year, no two successive vintages being probably identical in flavour and perfume, and it may happen that a season favourable to the vintage of one place is unfavourable to that of another: thus the good Port years rarely coincide with the good Claret years, for the heat which brings to maturity the grapes in the comparatively cold climate of Medoc, scorches the grapes of Alto Douro, and *vice versâ.*

The aspect of a vineyard must depend on the latitude and longitude of the district and on other circumstances. At Bordeaux a south-east exposure is preferred; in Germany, a south-west; in the north of France, a northern aspect is thought best. The locality should be a gentle acclivity, if possible, ascending from the bed of a river, the vapour from which, if not excessive, preserves the skin of the grape in a soft thin state, which is favourable to the passage of heat. High elevations are unfavourable, with one or two exceptions, such as the *Malaga* or *Mountain* wine of Spain, which is grown many thousand feet above the level of the sea. Vines bear wet badly, especially that of land springs.

The vines should be kept low, for it is found that the nearer to the ground the grapes grow, the more potent is the wine; the earlier also do the vines flower, and the grapes become ripe. Grapes on the lower branches are often ripe first, although shaded by the leaves from the direct rays of the sun. It has been suggested that the bouquet of wine is due to the bunches of grapes thus sheltered. The frosts of spring and the hail-storms of summer are injurious to the vine, as well as excessive wet in spring or autumn. There are also numerous insects which infest it.

The varieties of the vine are exceedingly numerous, between five and six hundred having been named.[1] The grape which ripens soonest is preferred, and it is generally found that red grapes ripen 10 or 12 days before the white. It is of importance in making wine that the grapes shall all have attained the same state of maturity. At Johannisberg and other famous vineyards on the Rhine, three successive gatherings of grapes are often made at considerable intervals, and every unsound grape is removed from each bunch as it is discovered. The state of maturity is one of the circumstances which determines the quality of the wine: for a brisk wine, such as Champagne, the grapes are gathered before they are quite ripe, but for the most esteemed German wines the gathering of the grape is deferred as long as possible in order to get rid of many free acids. This plan of late gathering has been found so successful, that new wines made from late gathered grapes have been found more soft and delicate than extremely old wines made from early gathered grapes. In some of the most celebrated

(1) In Mr. Busby's "Visit to the Vineyards of Spain and France," a list of 570 varieties is given.

vintages of Johannisberg the grapes have been hanging on the vines as late as October and November. In the warmer parts of the South of Spain and of France, and also at Tokay, the grapes are left for a long time upon the vines; the stalks being twisted to prevent the entrance of recent sap, while the thinner or watery portion of the sap evaporates from the fruit, which becomes dry and shrivelled and resembles raisins: from such grapes are made the *Vins de liqueurs*. On the Rhone some of the ripest grapes are selected and hung upon hurdles, or spread upon straw for 6 or 8 weeks: the sweet wine prepared from them is known as *Vin de paille*, or straw wine. A sweet luscious wine is sometimes made in Spain by boiling the must; the wine of Cyprus is thus produced, also the *Vino Cotto* of Italy (the *Vinum coctum* of the ancients), the original Malmseys of Candia, and other rich wines of the Grecian archipelago.

The chemical composition of grape-juice is complicated. The juice of the unripe grape, called *verjuice* or green juice, contains, according to Geiger, as follows: A deposit from the juice contained chlorophyll, wax, tannin, and glutinous matter: the filtered juice contained tannin, extractive, uncrystallizable sugar, gallic acid, free tartaric acid, (about 1·12 per cent.,) free malic acid (about 2·19 per cent.,) bitartrate of potash, malate, phosphate, sulphate, and muriate of lime. The juice was that of the white grape of good quality. The juice of the ripe grape called *must* contains, according to Proust, extractive or colouring matter, granular and uncrystallizable sugar, gum; glutinous matter, a little malic acid, citric and tartaric acid, and bitartrate of potash. Some other salts have also been found in must, such as tartrate of lime, tartrate of alumina and potash, sulphate of potash, chloride of sodium, and chloride of potassium. In some kinds of grapes there are racemates or paratartrates, which probably replace the tartrates. Traces of an oily matter are also found, derived either from the juice or from the seeds or husks; they have an important influence on the colour and flavour, or *bouquet* of the wine. The colouring matter of the grape resides entirely in the skin, except in the grape known as *Tintilla*, from which the *tent* wine of Spain is prepared: this grape is coloured throughout, and is used in dyeing: the French term it *teinturier* or *l'alicante*. The colour of the wine, however, does not depend upon that of the grape, for *Champagne* is made from a red grape, and *Sherry* is made from red and white grapes without distinction. The fermentation of the juice is promoted by the presence of the stalks, and if they and the skins are removed before the fermentation has proceeded far, they do not impart either colour or flavour to the wine, although the skins may be of a deep colour, the presence of alcohol being required to dissolve the colouring matter. They are removed at an early stage, in the case of the delicate red wines of Bordeaux; but are allowed to remain longer in the red wines of Portugal, which accounts for their greater astringency. The wine of Cahors has its colour deepened by the addition of a dye-stuff called *Raugome*, prepared by boiling for a few minutes 1 part of strong spirits of wine with 4 parts of must. The wines of the Moselle have a greenish colour, and those of the Rhine a yellowish colour. The broker judges of the colour of wine by placing a small quantity of it in a small silver saucer or *tambuladeira* (as it is called in Portugal): it is slightly raised in the centre. When this is agitated, the wine passing in a thin layer over the convex part exhibits the colour well. Casks for holding red wine should not be fumigated with sulphurous acid, which destroys the colour, but be rinsed out with spirits of wine.

Red wine is more delicate and liable to injury in the making than the white. If the grapes be gathered before they are sufficiently ripe, the wine is likely to be raw or *vert*, which is one of the greatest defects in wines, for they become *hard* by keeping. If the grapes be over-ripe, they are liable to putrefy before being gathered; the wine made from them works long in the barrels, and readily becomes sour. A few details of the processes of wine-making in the south of France will show the general method of conducting this branch of industry.

The celebrated wines of Bordeaux (known as *Clarets* in England) are for the most part grown on a long tongue of land situated to the north of Bordeaux, between the sea and the Garonne and Gironde: it is called *Médoc* (quasi medio aquæ), because it is nearly surrounded by water. It forms the north termination of that extensive region of sand known as Les Landes, and is nowhere more than one or two miles broad: it is raised from 50 to 80 feet above the river. The soil of Médoc is a light gravel, and in many parts, even where the best wine is produced, consists of rolled quartz pebbles mixed with sand. In fact, where scarcely a weed will grow, the stunted vine produces grapes of the first quality. This stony soil retains so much of the heat absorbed by day, that by its radiation at night, it works (*travaille*, as the people of the country say) as much by night as by day. The vine begins to yield grapes at 5 years of age, and is said sometimes to continue productive for 200 years. The wines are classed into growths (*crus*), but only a very small portion of the strip of land produces the *premiers crus*, and often within a few yards of the finest vineyards none but an inferior grape will grow. The Bordeaux wines of the first growth are known as the *Château Margaux*, the average quantity of which produced in one season varies from 140 to 160 tuns, (the tun or *tonneau* containing 4 hogsheads or *barriques*,) *Chateau Lafitte* 120 tuns, *Chateau Latour* 120 tuns, *Haut Brion* from 60 to 80 tuns. The last is properly a *Vin de Grave*, since it is grown on the Garonne above Bordeaux. Médoc wines of the second growth are *Mouton* (Lafitte), from 120 to 140 tuns; *Léoville*, the best of the wines of *St. Julien*, from 145 to 186 tuns; and *Rauzan* (Margaux), from 76 to 95 tuns. There are also *La Rose Gruau*, *Pichon*, *Longueville*, *Durfort*, *Degorse*, *Lascombe*, *Cos-Destournelle*; in all about 800 tuns. Wines of the third, fourth, and fifth growths, are many of them produced in the vicinity of the first-rate vineyards, without partaking of their excellences. So much, however, depends on the season, that when

this is highly favourable, second class wines may be raised to the rank of the first, and in bad seasons first class wines will fall below the second. In bad years, wines which would otherwise be sent to England are transported to Holland, or retained in France; and so much had this become the custom, that the proprietor of the vineyard of La Rose was accustomed to hoist on a flag-staff above his house the English flag in good years, the Dutch in middling, and the French in bad years. England receives more than one-half of the *premiers crus*, and very little of the inferior sorts; Russia takes a considerable quantity; Paris a small quantity of the best; wines of the second quality go to Holland; and the third sorts, or *vins ordinaires*, are chiefly consumed in France. The wines for the English market are mixed with strong bodied Rhone wines, chiefly with *hermitage*. The average price of a hogshead or barrique of genuine wine of first growth, in the cellar of the first houses of Bordeaux, is 50*l*., which, with carriage, duty, bottling, &c., amounts to 80*l*., or rather more than 70*s*. a dozen.[1]

In making Claret, the wine-vessels are first cleaned, and rinsed with the strongest spirits of wine, or even with brandy, and the grapes being gathered, the rotten bunches, and those which are not ripe or are withered, are picked out. A *cuve-mère*, or mother-cask, is first prepared with the best fruit: the grapes are put in without their stalks, and without treading them, in a layer from 15 to 20 inches deep; 2 gallons of old Cognac or Armagnac is poured on them, another layer of picked grapes, then 2 more gallons of brandy, and so on until the cask is full. From 2 to 4 gallons of spirits of wine are lastly added, 4 gallons being used for a vat of from 30 to 36 tuns. The quality of the vintage, however, regulates the quantity of brandy or spirits of wine required, a larger proportion being used if the quality is bad. In bad years, when the grapes do not contain a sufficient quantity of saccharine matter, it is now customary to supply the defect by the addition of glucose or starch sugar. When the cuve-mère is filled, it is closed securely and covered with blankets, and left for 3 or 4 weeks. In order to ascertain the progress of the fermentation, and the exact time for racking off, a small brass cock is inserted at the side of the vat, at about the height of one-third of its depth from the bottom. When the liquor has become cool and tolerably clear, it is fit for drawing off. While the fermentation is going on in the mother-cask, the vintage is continued in the usual manner; that is, as the grapes are brought in and picked, they are trodden in the press,[2] and put with their stalks into vats, where the fermentation takes place naturally. The vats are filled to within 12 or 15 inches of the top, the vacant space being left in case of overflow, which sometimes happens when the grapes have attained perfect maturity. The stalks, skins, and seeds, which float on the surface of the wine, form what is called the *chapeau*. The vats are lightly covered and left to ferment; they are carefully examined about twice a-day, and in from 8 to 12 days, according to the goodness of the vintage, they may be racked. The time for racking is a critical point; for if the wine be left too long upon the lees, or with its crust or chapeau on, it will imbibe the disagreeable flavour of the stalks; if racked off too soon, the wine is liable to fret in the barrel and become sour. The wine is racked off into barrels, (prepared by scalding and rinsing with a little spirits of wine,) which are filled about $\frac{2}{3}$ or $\frac{3}{4}$; the mother-cask is then emptied, and equal portions of its contents are poured into the barrels, a quantity being reserved from the mother-casks to supply the loss which the barrels may sustain from evaporation or ullage. The barrels are left 8 days without being bunged, but the bung-holes are lightly covered with a stone or piece of wood. They are filled up every 2 days, and when bunged, every 8 days, until the wine is in such a condition that the cask may be kept with the bunghole at the side: this takes at least 18 months.

In making white wine, the grapes are trod, and when taken from the press the stalks are separated, and the juice, skins, and seeds, are put into casks to ferment. When the wine has been racked off, care is taken to keep the barrels full by filling up once or twice a-week.

It will be seen that the production of wine involves fewer and simpler processes than the brewing of beer. The wine, the result of the above operations, should be clear and transparent, of a fine soft colour, and a lively smell, balsamic and slightly piquante in taste, filling the mouth, not irritating the throat, gently warming the stomach, and not quickly affecting the head. The *sève* or flavour of the wine, and the bouquet or odour, are properties resulting from very different sources. The flavour appears to be due to the alcohol and the aromatized particles set free by the warmth of the mouth and stomach. The bouquet is due to the generation of a peculiar ether called *œnanthic*.[3] In some wines, the sève and the bouquet are produced only by age. A fictitious bouquet, how-

(1) Murray. "Handbook for Travellers in France."

(2) An English visitor to one of the vineyards of this district thus describes the operation of pressing:—The music strikes up, and the first cart tumbles its precious load through a wide sort of arched window into the great cistern, which stretches along just below the level of its sill. There were three of these openings in the length of the building; and each cistern was manned by sixteen men in merely their white shirts, and short breeches tucked up above the knee, showing the brawny legs and bare feet which were soon to tread a measure to the old fiddler's lively melodies. A strange effect it had to our English eyes when these rough-looking beings, taking their places opposite to each other, began a set of quadrilles in a most decorous manner, at every step crushing down the once beautiful fruit, whose juice runs out at an aperture in one corner into tubs, beside which a man watches lest they should overflow. Before the ball commences, there is a very large wire frame or cullender placed over the shallow cisterns, in which the men rapidly separate the stalks from the fruit; the latter falling through, and the stalks being carried to another cistern, where a man with a small kind of rake picks off any grapes remaining on them. These stalks are then piled up in a press, and the liquor they yield makes an inferior drink for the lower classes. As the juice streaming from the presser's cisterns filled the tubs, they were borne away on poles between two men, and thrown into great vats, with the skins of the grapes, where all is left to ferment.—*Chambers' Edinburgh Journal*, No. 214, N.S.

(3) *Flower of Wine*, from οἶνος, wine, and ἄνθος, a flower.

ever, is sometimes given by adding several species of sage and rue to the fermenting liquid, or by hanging in the cask into which the wine has been racked, for about 15 days, a muslin bag containing 2 drachms of powdered orris-root. A fictitious flavour is also given by means of raspberry-brandy.

It was formerly supposed that the bouquet of wines was derived from the grapes themselves; and hence it was, and we believe still is, customary to suspend some of the ripest and most odoriferous bunches of the grapes in the cask after the first fermentation had subsided. It has, however, been shown by Pelouze and Liebig, that the smell and taste which distinguish wine from all other fermented liquors are due to an ether of a volatile combustible acid, resembling one of the fatty acids, and named *œnanthic ether*, as already noticed. Œnanthic acid is represented by the formula $C_{14}H_{13}O_2$, and the addition to this of C_4H_5O, gives $C_{18}H_{18}O_3$ as the composition of œnanthic-ether. This ether was first separated from the wines of Burgundy, and it has been found with amylic alcohol, or potato-spirit oil, in the products of the distillation of the grape-stalks of Montpellier. It has been supposed that the odorous compounds which form the bouquet of wines originate in the fatty acids of the grape, which, by oxidizement, are converted into the more powerful acids better capable of forming ethers. It appears, however, to be only in liquids which contain other very soluble acids, that the fatty acids and œnanthic acid are capable of entering into combination with the ether of alcohol, and of thus producing the volatile odorous compounds. This ether is found in all wines which contain a free acid, and does not exist in those which contain no acid. Tartaric acid, therefore, seems to be the means by which the bouquet in wines is produced. If a different organic acid be present, such as the acetic, the peculiar taste and odour will be wanting. The wines of warm climates have no odour; those of France have it in a marked degree; and it is strongest in Rhenish wines. Those grapes which are grown on the Rhine, and known as the *Riessling* and the *Orleans*, ripen late, and seldom attain maturity; they afford the strongest bouquet, and contain a proportionately larger quantity of tartaric acid. Grapes which ripen earlier, as the *Rulander*, yield a large proportion of alcohol, and resemble Spanish wines in flavour, but have no bouquet.

The fermentation of the must is best carried on in large casks, covered over to prevent the escape of carbonic acid, alcohol, and aroma. The time required for the fermentation depends on the kind of wine and the temperature. In the Champagne district, the grapes required for one cuve are all pressed within a couple of hours, and left from 6 to 18 hours, when the must becomes quite clear, an event which is watched for with great anxiety. The must is drawn off into well-sulphured casks, and put into underground cellars; the bung-hole is covered with a flintstone; and the yeast which overflows is occasionally removed, until December or January, when the wine can be tasted and proved. In this condition it is sold, and then undergoes the operation of *fining*.

The primary or active fermentation is succeeded by a secondary or insensible fermentation, a continuation of the first, but which requires careful management. The contact of the air will excite fermentation in the juice of the grape, the sugar of which will be converted into alcohol and carbonic acid. [See FERMENTATION.] In addition to these products, an insoluble nitrogenous substance called yeast is also formed from the azotised constituents of the grape-juice; also called gluten, or vegetable albumen. This yeast has the property of inducing fermentation in a new solution of sugar, whence it is called a *ferment*. Gluten appears to act towards sugar as diastase does towards starch, by imparting that impetus to it which enables it to alter its condition. When gluten and sugar are both present in a liquid, fermentation proceeds until the decomposition of one or other constituent is complete. When the quantity of ferment is too small in proportion to the sugar, its putrefaction will be effected before the whole of the sugar is converted into alcohol and carbonic acid. This happens in the case of sweet wines which contain unchanged sugar, the cause of its decomposition being wanting, namely, contact with a body in a state of decomposition. When, however, the quantity of ferment predominates, some of it remains after the whole of the sugar has been transformed, and then its decomposition proceeds very slowly in consequence of its insolubility in water. The grape-juice of different climates contains very variable proportions of free acid and of sugar; but the quantity of azotised matter in the juice seems to be tolerably constant. As the presence of sugar, in wine in an unchanged state, produces a sweet wine in which the conditions required for further change are absent; so, on the contrary, those wines which contain not an excess of sugar, but variable quantities of undecomposed gluten in solution, are thus liable to become converted into vinegar if access of air be not prevented; for if air be present, the gluten absorbs oxygen and becomes insoluble, and its oxidation is communicated to the alcohol, which is thus converted into acetic acid. If the wine be left undisturbed in casks with a very limited access of air, and at a cool temperature, the oxidation of the azotised matter goes on without the alcohol undergoing the same change, a higher temperature being required to enable the alcohol to combine with oxygen. So long as the wine in the stilling casks deposits yeast, the addition of sugar will continue the fermentation; such, however, is not the case with old well-layed wine, because a substance in the act of decomposition, such as yeast, is no longer present in it. In hotels, and places where wine is drawn gradually from the cask, and a proportionate quantity of air introduced, its conversion into acetic acid is prevented by adding a little sulphurous acid, which, combining with the oxygen of the air in the cask, or which is dissolved in the wine, prevents the oxidation of the organic substance.

The phenomena of fermentation[1] may be usefully

(1) On this subject we have chiefly followed Liebig's views, as expounded in his "Chemistry applied to Agriculture and Physiology." 1847.

recapitulated in the following form:—Grape-sugar consists of carbon, hydrogen, and oxygen; the presence of a ferment disturbs the relative proportion of the atoms, and leads to the production of carbonic acid, which for the most part escapes in the form of gas, and alcohol, which remains in solution. The number of atoms of carbon and oxygen is thus diminished. For example:—

Three atoms of sugar = 3 atoms hydrogen, 3 atoms carbon, 3 atoms oxygen, decomposed;
One atom of alcohol = 3 atoms hydrogen, 2 atoms carbon, 1 atom oxygen, formed;
One atom of carbonic acid = 1 atom carbon, 2 atoms oxygen, formed.

So long as sugar is present, the power of the gluten or ferment is exerted in converting it into alcohol: when no sugar is left, it acts on the alcohol, and converts it into vinegar by the acquisition of 1 atom of oxygen. This action, however, is not immediate, but is brought about by means of a substance termed *aldehyde*, which consists of alcohol deprived of 2 atoms of hydrogen, the hydrogen being oxidised at the expense of the oxygen in contact with it, water being formed and heat evolved. The aldehyde has a great affinity for oxygen, combines directly with it, and produces acetic acid. The formulæ for these changes are thus stated in Kane's "Elements of Chemistry:"—

Grape sugar	C_{12}	H_{14}	O_{14}	
This contains exactly the elements of 4 atoms of carbonic acid gas	C_8	—	O_2	disappears.
and 2 atoms of alcohol	C_4	H_6	O_2	
The formation of acetic acid from alcohol consists of two stages: 1st, the abstraction of hydrogen, by which aldehyde is formed; and 2dly, the addition of oxygen, by which acetic acid is produced. Alcohol	C_4	H_6	O_2	
Gives by...	—	H_2		
Aldehyde	C_4	H_4	O_2	
And this gives by...		+	O_2	
Hydrated acetic acid	C_4	H_4	O_4	
Or hypothetic dry acetic acid..	C_4	H_3	O_3	

The exclusion of atmospheric air from wine, its preservation at a low temperature, and the manipulations required for its maturity, are included under the operations of *racking*, *sulphuring*, *fining*, *mixing*, *bottling*, and *cellaring*.

The careful exclusion of wine from contact with the oxygen of the air is necessary to prevent the setting in of the acetous fermentation. When once the vinous fermentation has begun, however limited the supply of oxygen, it cannot be arrested so long as any saccharine matter remains in solution. It does in fact go on, and impart those valuable properties which are so much esteemed in what is called *old wine.* When the quantity of saccharine matter is large, and that of the gluten small, the latter will be wholly decomposed, and only a small portion of the sugar be converted into alcohol, the remaining sugar being in solution, and forming the constituent of a *sweet wine.* This excess of sugar will even serve as a preservative to the wine, air being excluded. Thus we hear of certain sweet wines having been kept for long periods of time. *Mountain* wine, buried at the time of the great fire of London, and taken up in the year 1811, was found to be of superior quality; *muscadine* wine has been kept 200 years. In the preparation of such wines an excess of sugar may be added during the first fermentation, to ensure the decomposition of the whole of the ferment. The juice of the grapes grown in colder climates, however, which is much less rich in saccharine matter, furnishes a wine which is liable to become soon *pricked*, (that is, affected with the first symptoms of the acetous fermentation,) in which case the addition of sugar, so far from acting as a preservative, would hasten the mischief. The transformation of the whole of the sugar into alcohol produces what is called a *dry wine;* to effect this result, the fermentation is excited from time to time by *rolling* the cask, or returning the wine to the cask to *feed*, as it is called. A portion of undecomposed gluten in the lees acts as the excitant. In this operation care must be taken not to push the fermentation too far, or to allow an excess of gluten in the cask. By way of precaution, the bung-hole is left open for some months, and the cask is frequently filled up, so that the excess of yeast may escape out of the cask. After this has gone on for some time, the wine, if of good quality, is racked off into a clean cask previously *sulphured;* that is, just before the wine is racked off into it, a rag steeped in sulphur is set on fire, and introduced at the bung-hole of the cask, the object being to convert the whole of the oxygen of the air of the cask into sulphurous acid, and it is generally stated in books on the subject that this object is completely accomplished. This, however, is a mistake, for as soon as a small portion of sulphurous acid is generated, it forms with the remaining air of the cask a mixture which will not support combustion. The extinction of the sulphur flame, which is a mark to the operator of the success of his expedient, proves in fact nothing more than the existence within the cask of an atmosphere which will not support the further combustion of sulphur, but does not prove the complete conversion of oxygen into sulphurous acid; for there is probably two-thirds of the oxygen of the cask still unchanged, and still capable of producing that action on wine which it is the object of this process to avoid. Some persons employ sulphate of potash, in the proportion of a drachm of salt to the pipe of wine, for the purpose of absorbing oxygen. Black oxide of manganese and other substances have been empirically recommended. In racking off the wine, the upper portion or cap, and the lower portion or lees, should be rejected: they may be afterwards used for making brandy or vinegar according to circumstances.

Good wines may be racked as often as three times during the first year; but as racking does not get rid of those particles which neither sink to the bottom nor rise to the surface, but remain suspended in the wine, the process of *fining* is resorted to previous to bottling. There is much empiricism connected

with this operation—a variety of powders being recommended, which, if we are to believe their inventors, would almost have the effect of converting a bad wine into a good one. The common wine-finer is either isinglass or white of eggs.

In order to confer *firmness* or *durability* on wines, the process of *mixing* is resorted to. For example, a wine of good quality, but which, in the judgment of an experienced wine-grower, would be liable to turn off on keeping, has mixed with it in certain proportions wine which is eminently distinguished by its firmness, the result being a wine of medium quality well adapted to certain markets. The mixing of wines requires tact, skill, and judgment, and is one of the ordinary operations of the wine-grower. It is apt, however, in the case of some wine-merchants or venders of wine, to degenerate into *doctoring*, or making up wines as physic is made up, from various sources, according to certain recipes. The doctoring of wines, however, is practised on a magnificent scale in Portugal, where, in the port-wine prepared for the English market, and required by Portuguese law to be "black, sweet, and strong," the blackness or colour is supplied by the juice of the elder berry, which is largely cultivated in the wine districts for the purpose; the sweetness is produced by checking fermentation at an early stage; and the strength by mixing large quantities of brandy with the unripe wine in the cask. The addition of brandy to wines intended for the English market is made under the pretext that the wine would not otherwise bear the voyage: this is certainly untrue, and we have the assurance of an experienced importer of wines, that "there is no port-wine produced that cannot be, and may not be, shipped to any part of the world, and that will not keep for a certain time." Particularly delicious wines, which are called port-wines, but the character of which is very different from what we understand in England by that name, are asserted by the same authority to be capable of being shipped to this country, and if drunk off in draught, would keep as they keep in their own native country, for one, two, or three years, or if purified and bottled, would keep as in Oporto, without a single drop of brandy, for 16 or 17 years.[1] The addition of brandy to wine injures its vinosity, or that peculiar combination of alcohol with certain organic vegetable compounds which renders wine, when taken with moderation, a wholesome and a natural drink. The added brandy does not combine with any of the constituents of the wine, but exists in a free state, and produces those injurious effects on the human system which are supposed to be limited to dram-drinking.

One of the objects of mixing wines is to produce a compound possessing qualities which do not exist in any single wine. The mixing of Rhenish wines is a delicate and difficult art; but of all wines, sherry is that which is most mixed with the vintages of different years. The wine-merchants of Xeres always retain in store a quantity of old fine wine, and the proportion in which it is mixed with newer or inferior wines depends upon the market to which it is to be expedited, and the price. The quantity thus drawn off from the oldest and finest casks is made up from casks which most nearly approach them in age and quality; and these in their turn are filled up from casks which resemble them in similar qualities, —so that a cask of wine 50 years old may be made up from the vintages of 30 or 40 seasons. After the mixing, fermentation is usually partially renewed in the cask; this is called *fretting*, and the process of combining one wine with another is called *fretting in*. Fermentation is sometimes excited by rolling or agitating the cask. The processes of fining and racking are repeated in order to get rid of ferment and colouring matter, the presence of which might endanger the durability of the wine, and injure its appearance. The wine is now left in the cask, or *in the wood*, as it is termed, to mature. The time required for this important effect is variable. It is greatly assisted by an elevation of temperature; and it is not uncommon to send wines, such as sherry and Madeira, on a voyage to a warm climate, and to leave them there until maturity has been obtained. In Madeira the wine-stores are often situated in the top floor of a house, in order to have the benefit of the sun's rays, and it is not unusual to send the wine to this country by way of the West Indies. While the wine is in the wood, a considerable portion of its watery contents evaporates, and there is some loss from ullage. The amount of loss from evaporation varies with the climate, and the kind of wood of which the cask is made. The loss sometimes amounts to one-twelfth per cent. per annum, as is the case with wines contained in casks of Spanish chestnut, which is an objectionable wood on account of the taste which it imparts to the wine. Memel or Dantzig oak is used for port-wines. The ullage is greatest in new casks, and hence old ones are preferred, provided they are sound and sweet. As the watery particles evaporate, matters which they held in solution are deposited, in consequence of their insolubility in alcohol. These form what is called tartar, which consists of an impure bi-tartrate of potash and other substances. The colour changes; that of red wines generally becoming deeper, as in the case of Médoc, but some paler, as in port; hence, in order to give the appearance of age to port, *white port* (or that from which the skins of the grapes have been removed at an early stage of fermentation, before sufficient alcohol has been generated to dissolve out the colour) is added; and to clarets, the black wine of Cahors is added. It has been supposed that wine ripens better in large than in small casks, and hence such enormous tuns as those of Heidelberg have been constructed. The celebrated Heidelberg tun constructed in 1751 is 36 feet long, and 24 feet high, and is of the capacity of 800 hhds., or 283,200 bottles. When any of the wine is drawn off, care is taken to fill up the casks with wine of the same quality—and if this is not to be had, olive oil is

(1) Mr. J. J. Forrester's Evidence contained in "Report from the Select Committee on Import Duties of Wines." 1852.

used—in order to prevent the contact of the oxygen of the air with the wine, which would cause it to degenerate into vinegar. The surface of the wine would also soon become covered with a fungus if this precaution were neglected. In damp cellars, the casks are liable to become affected with dry rot, which may thus lead to the loss of their contents. The mouse-skin Byssus (*Racodium cellare*) is a fungus which grows only in dry cellars, and is regarded as an indication of the soundness of the casks. When the wine has been in the wood for a certain time, it improves in alcoholic strength and other qualities; but if left too long, alcohol, instead of water, will begin to evaporate: the wine is then fit for bottling. Previous to this operation, however, the wine undergoes fining, and it is left for 10 or 15 days to become clear. The bottling should take place in March or October. Bottles should be quite clean, the corks sound and well driven in, so as to expand below the contracted part of the neck of the bottle, and completely exclude the air. To protect the corks from the attacks of insects, the exposed part is often covered with a waxy composition; but the wines themselves, especially the dearer and sweet wines, will corrode the corks, which therefore require to be renewed from time to time. In the case of Italian wines in bottle, it is not unusual to omit the cork altogether, and fill up the neck of the bottle with olive oil. Red wine in bottle deposits a crust on the side in contact with the sawdust of the cellar. Champagne requires to be corked twice. It is first bottled after remaining only three years in the cask; then corked, and the bottles placed in an inclined position, with the necks downwards. A considerable deposit takes place, which, when completely formed, is removed by withdrawing the cork from the bottle while in its inclined position; a portion of the wine rushes out carrying with it the lees, the remaining clear portion of the wine being intercepted by the operator closing the mouth of the bottle with his fore-finger, at the moment when the last particle of lees has passed the neck. The bottle is then filled up with a solution of sugar-candy in one of the ordinary wines of the country, then corked, wired, and the neck sometimes covered with tinfoil. In this condition champagne may be kept from 10 to 20 years. The loss of bottles by bursting, in the champagne trade, is said to amount to from 20 to 30 per cent. and a machine has been invented for testing their strength, which ought to be equal to bear the pressure of from 25 to 35 atmospheres. The peculiar care required in the manufacture of such bottles causes their price to be nearly double that of ordinary bottles. In France alone, the general wine bottle trade is estimated at above 60,000,000 of bottles annually, and the value at more than half a million sterling.

The almost endless diversity of wines is produced by variations in the proportions and modes of combination of a comparatively small number of ingredients. These are *water*, *alcohol*, *œnanthic ether*, (forming the *bouquet*,) *sugar*, *gum*, *extractive* or *colouring matter*, *tannin*, *gluten*, certain acids, of which *tartaric* is the chief, and certain salts.

Wines which contain much alcohol are termed *strong* and *generous;* when the proportion of alcohol is small, they are called *light* or *weak;* when the proportion of sugar is large, they form *luscious wines*, *sweet wines*, *vins de liqueur;* when little or no undecomposed sugar is present, the wines are said to be *dry;* if a considerable proportion of free acid be present, they are called *acid* or *acescent* wines. The presence of carbonic acid produces *sparkling* or *effervescent* wines, called *mousseux* by the French, and *schaumweine* by the Germans.

The quantity of alcohol in wines has been ascertained by analysis. Many years ago, Professor Brande instituted an extensive inquiry on this subject, the results of which are given in his "Manual of Chemistry." In 1838, Professor Christison made some experiments, some of the results of which are given in the following table. The second table, showing the amount of alcohol in French wines, is by M. J. Fontenelle.

Names of Wines, &c.	Alcohol by weight per cent.	Proof spirit by volume per cent.
Port, weakest	14·97	30·56
,, mean of 7 wines	16·20	33·91
,, strongest	17·10	37·27
White port	14·97	31·31
Sherry, weakest	13·98	30·84
,, mean of 13 wines, not long in cask	15·37	33·59
,, strongest	16·17	35·12
,, mean of 9, long in cask in East Indies	14·72	32·30
,, Madre da Xeres	16·90	37·06
Madeira, long in cask in East Indies	14·09	30·80
,, strongest	16·90	37·00
Teneriffe, long in cask in Calcutta	13·84	30·21
Sercial	15·45	33·65
Dry Lisbon	16·14	34·71
Shiraz	12·95	28·30
Amontillado	12·63	27·60
Claret, first growth, 1811	7·72	16·95
Château-Latour, first growth, 1825	7·78	17·06
Rosan, second growth, 1825	7·61	16·74
Vin Ordinaire, Bordeaux	8·99	18·96
Rivesaltes	9·31	22·35
Malmsey	12·86	28·37
Rudesheimer, first quality	8·40	18·44
,, inferior do.	6·90	15·19
Hambacher, first quality	7·35	16·15
Edinburgh ale, unbottled	5·70	12·60
,, two years bottled	6·06	13·40
London porter, four months in bottle	5·36	11·91

Wines.	Alcohol by volume per cent.	Wines.	Alcohol by volume per cent.
Bamyulls	21·96	Mèze	18·60
Rivesaltes	21·80	Bezières	18·40
Colliouvre	21·62	Lunel	18·10
Lapalme	20·93	Montpellier	17·65
Mirepeissel	20·45	Carcassone	17·22
Sallces	20·43	Frontignan	16·90
Narbonnes	19·90	Bourgogne	14·75
Leriguan	19·46	Bourdeaux	14·73
Leucate de Fiton	19·70	Champagne	12·20
Montagnac	19·30	Toulouse	11·97
Nissan	18·80		

Such inquiries as those which lead to the foregoing results, lose much of their value from the fact that the alcohol naturally produced by the fermentation of the grape juice is increased in quantity by the addition of brandy. It is a popular notion, in this country at least, that wines cannot be kept unless brandy be added, and probably no housekeeper would think of bottling her currant or gooseberry wine without the addition of a certain proportion of brandy. That the practice is unnecessary is proved by the fact that the light Rhenish wines, which will keep for a century, are never brandied. If the causes of acetification be present in the wine, or the wine be not properly protected from the oxygen of the air, the addition of alcohol cannot prevent it from *turning*. It will be seen by reference to Acetic Acid, that the stronger the liquid is in alcohol, the stronger will be the resulting vinegar, and that the change from alcohol to acetic acid may be brought about in a few hours.

The brandy used in the adulteration of port-wine is distilled from the common ordinary wine, or *vin ordinaire* and *petit vin*. Nine pipes of this wine produce one pipe of spirit. This brandy when old is of very fine quality: it is very cheap,—so much so that, in some years when the vintage is abundant, a pipe of it has cost less than a pipe of wine grown within the district which produced the finest wine.

The custom of adding strong spirit to wines intended for the English market, may have been favoured partly by the climate of England, partly by the love of highly stimulating drinks among the people. At any rate, the taste for strong ports and sherries seems to be so confirmed, that supposing the duty on foreign wines were reduced from 5*s*. 9*d*. to 1*s*. per gallon, as has been proposed, it may reasonably be doubted whether the light wines of the Continent would ever come into general use. To show the extent to which the wines of Portugal are brandied for the English market alone, we may again refer to Mr. Forrester's evidence:—

"87. You have said that the quantity of brandy in a pipe of port-wine depends upon the nature of the order for it. Now what is the minimum, and what the maximum quantity of brandy in a pipe of port-wine when it reaches this market?—If the wine be perfectly fermented, as a matter of course one-half the proportion of spirit would be requisite; if it be not fully fermented, then double the proportion; if it be of the very light and simple character to which I have before referred, hardly any is requisite.

"88. Will you state it in gallons?—The minimum? There is no port-wine, to the best of my belief, comes to this country that has less brandy in it, that is to say, adventitious spirit, than half an almude (16 quart bottles), which is about three gallons to a pipe—but that is a very small per centage; indeed the other wines, the richest of all that I have mentioned (viz. the jeropiga), is 33⅓ per cent; and the heavy brandied rich wine, so denominated, cannot ever contain less than from 15 to 17 gallons to each pipe of 115 gallons."

The wine-drinker in this country cannot ever be certain that the very large admixture of brandy made to his wine in Spain, Portugal, or Sicily, forms the whole. The dealer in this country not unfrequently adds a further dose of brandy or whisky to his wine, with the intention of imparting to it those symptoms of age which are found in a lighter colour, and a lining of crust in the bottle, formed by a precipitate of colouring matter on the addition of the raw spirit. But how is the bouquet, which time alone produces, to be formed without his aid? What will not art, aided by science, accomplish? A drop or two of sulphuric acid, added to each bottle of wine, will in a few hours produce a lively bouquet. The sulphuric acid, by its action on a portion of the alcohol of the wine, generates a small portion of sulphuric ether [see Ether] which supplies the place of the real bouquet, produced by the conversion of the œnanthic acid into œnanthic ether, which by the natural process requires years for the tartaric acid to accomplish. We do not, however, pretend to a knowledge of all the wine-dealer's secrets, or we might show how in this manufacturing country port-wine is not excluded from the list of manufactured goods. But we may state that large quantities of fictitious port-wine are made up from cider as a basis, a cheap French red wine, brandy or whisky, sloe-juice, for the flavour of "fine old rough port," logwood for the colouring matter, and sulphuric acid for the bouquet. In this respect, as in other matters of taste, the French are more skilful than the English manufacturers. It is stated, that at the port of Cette, in France, any known wine can be manufactured at a very short notice, in any quantity, and that the imitation is very skilful. It would seem, however, that the English are improving in the art, from the following anecdote related by Mr. G. R. Porter:—"A friend of mine who invented, some years ago, a substitute for corks, which were made with India-rubber, stuffed with wool, was asked if he could make some to resemble Champagne corks, and he undertook to do so, and was desired to make a small quantity by way of trial. Two days after he had sent them in he had a note from the parties requesting to see him; he accordingly went, and they produced a bottle of this *quasi* Champagne wine, with the comment that it was in excellent order; he found it very palatable; but he could not make out how the corks which he had supplied to them only two days before, could possibly have been used for the corking of Champagne wine, and there can be no doubt it must have been all made in this country." We are satisfied that little or no improvement will take place in the wine trade of this country—at least so far as regards the supply to the middle classes—until an improved taste arises among them, and they cease to consider a bottle well chalked on the outside, well crusted within, corks deeply stained with logwood, and an odorous, hot, and exciting liquor as necessary to the credit of their cellar.

The wines of France and the Rhine are generally contemptuously styled by the Englishman *light* and *sour;* but he should remember that this lightness is one of the very qualities which ought to recommend

wine. The 8 or 9 per cent. of naturally combined alcohol in Rhenish wine, and an abundant bouquet, are sufficient gently to stimulate, and not to intoxicate. Intoxication is seldom or never seen on the Continent, while it is so frequent in the British islands as to constitute a national feature and a national disgrace. And, with respect to sourness, this is produced chiefly by the presence of *tartaric acid*, which seems so to correct and qualify the alcohol, that it no longer produces diseases of the liver as our brandied wines do. The combined effect of the alcohol and tartaric acid is to exalt the digestive functions, to increase the appetite, and improve the health; and it is remarkable how soon English visitors to the Continent, who at first turn with disgust from this "*vinegar*" as they call it, not only become reconciled to it, but drink it with a relish which they never knew in the case of their accustomed port and sherry.

Of the other acids sometimes contained in wine, *malic acid* is seldom found, except perhaps in the juice of grapes grown in wet seasons. *Citric acid* may be present in wine made from unripe grapes. *Oxalic acid* may sometimes be found; but this is doubtful, except in the case of wine made from garden rhubarb. *Acetic acid* is most likely to be present in the low, poor wines of northern countries; but, as we have already seen, is liable to be present in all wines by contact with oxygen, especially in wine on draught, if the consumption be small. In order to disguise its presence in wine, a highly dangerous poison, sugar of lead, is frequently added—a compound which may sometimes be formed in wine in bottle, from the presence of some of the shot used in cleaning the bottles. *Carbonic acid* is present in champagne and sparkling wines. *Tannic acid*, derived from the seeds of the grapes, imparts to port its roughness and astringency; it is also present in Tent, but is concealed by the sweetness of that wine. *Tartrate of alumina and potash* occurs in some of the German wines. *Argol* or *bi-tartrate of potash*, precipitated with some of the colouring matter, is however the most common salt in wines. Some wines contain small portions of *sulphate of potash*, and also of the chlorides of *sodium* and *potassium*.

Sugar is the characteristic ingredient in sweet wines, of which the most celebrated are the *Rivesaltes*, *Lunel*, and *Frontignan* of France; the *Paxarete*, *Tent*, and *Malaga*, of Spain; the original *Malmsey*, of the Grecian Archipelago; the wine of Madeira; the *Constantias;* the *Tokay*, and *Lachyrma Christi*, and *Lissa*, of Sicily. Such wines are usually taken in small quantities as liqueurs, and wormwood and other bitters are frequently added to them, to modify their unwholesome effect. Much of the sugar, however, disappears with age, and some of them, such as those of *Bergerac*, actually become dry wines in the course of six months. Manufactured imitations of the *vins de liqueurs* are very common, and it is difficult with this class, as with other classes of wines, to procure them genuine in England, except from first-rate houses and at high prices.

The wines of Portugal are required by law to be arranged into four classes, for which purpose tasters or inspectors of wine are appointed. The process of classifying wine is thus noticed by Mr. Forrester:—"No sooner are the wines housed, no sooner has the farmer to feel grateful to Providence for an abundant harvest, than the wine companies' tasters flock up to the Alto Douro in a shoal, pounce down upon his property, sample every one of his large vats, mark and number those samples (and too often for half-a-crown any quality of wine, in any bottle, might be substituted for those samples); and then the tasters are congregated in a large room, where smoking and other little amusements of the kind, if not permitted, are certainly tolerated; and there, one after the other, the samples are only too often submitted to the judgment of those men, many of whom have no knowledge whatever of wine, much less of wine five or six weeks old." Wine of the "first quality" is required by law to have "body, flavour, colour, and richness to spare:" this wine is used for doctoring other wines. Wine of the "second quality" is required to be a beautiful, pure, simple, unloaded wine; but as it will not serve for a doctor, or for blending or *cutting* with other red wines, it is not allowed to be shipped to this country at all, nor to any port in Europe. Wine of the "third quality" is a simple light wine, with little body and colour, but which is admirably adapted for table drinking, off-draught, and may be shipped with little or no brandy at a very cheap rate. This is the only wine used to any extent from royalty to the peasant in Portugal; and no other country is allowed by law to taste this racy, health-inspiring wine. The "fourth quality" is set aside as *refuse*, and is generally used for the purposes of distillation.

The wine-merchants of Portugal evade the law which forbids the export of any but the so-called first quality wine, by obtaining *bilhettes*, or permits for exportation, under cover of which they bring down to Oporto fine wines grown by themselves, in place of the so-styled first quality. To this species of smuggling England is indebted for ever obtaining anything like good port-wine.

The duties laid on wines by the Portuguese government tend further to limit the exports to Great Britain. "By the original law, the sum of 12 milreis was imposed as an export duty on all wines sent to Europe; and yet they imposed 7 per cent. additional, and a second addition of 5 per cent., with another of 3 per cent. to pay the salaries of the custom-house clerks, and a further addition of 10 per cent. for the loss on government paper: the 12 milreis thus swell into the sum of 15 mil. 190 reis, or 3*l.* 8*s.* 4*d.*, instead of about 2*l.* 18*s.* These are the duties on the wines to Great Britain and to the rest of Europe, of which one-half is a bonus awarded for the support and maintenance of the Royal Wine Company monopoly." The duties to America, Asia, Africa, and Australia, and to every country out of Europe, are only 100 reis, or 5*d.*, with the additional impost of 7 per cent., and 5 per cent. as above. The sum total, therefore, paid on those wines which are of

the same character as ours, is 6*d.* a pipe, and no permits are requisite. The Americans thus pay 6*d.* for the pipe of wine, while the British subject pays imposts and duties to the amount of 6*l.* per pipe, before the wine is allowed to leave Portugal. The system of *bilhettes* is connived at by the government, and they are bought and sold in the market like shares or railway scrip.

The taste for sweet wines is in some cases peculiar, a particular kind of wine being sometimes manufactured for a particular district or country. Thus the Portuguese prepare for America a compound called *Jeropiga:* it consists of two-thirds must or grape-juice, and one-third spirit (distilled from port-wine, and 20 per cent. above British proof), together with sweetening matters of various kinds, and elderberry juice for imparting a dark colour. This mixture is largely used in America for making negus, and sells at double the price of wine; being very sweet, very strong, and highly coloured, nothing more is required for negus than the addition of hot water. Jeropiga is also employed in Portugal for "bringing up character" in port-wines.

The wines of Spain are much less fettered by Government restrictions than those of Portugal. The Government allows bottles to be imported, for the purpose of being filled with wine for exportation. Casks and staves are also freely admitted, to supply the defective cooperage of the country. The absence of roads, and the difficulties of transport, nullify to a great extent the natural advantages of this fine country. There are many pure and beautiful wines which can only be removed from the places of their growth in skins on the backs of mules; and as the skins impart an unpleasant taste to the wine, this method of transit cannot be adopted.

In cases where roads have been formed, the traffic is so badly organised that those who conduct it are in the habit of tapping the casks, drawing off considerable quantities of wine, and filling up the casks with water. It is to be hoped that the system of railroads, which is being slowly introduced into Spain, will facilitate the transit of wine and other products. The Cadiz wine district comprises upwards of 25,000 acres, and includes Xeres, Port St. Mary's, Tribugena, San Lucar di Barrameda, Chipiona, Rota, and Puerto Real. The soil of the higher ground close to Xeres de la Frontera is composed of carbonate of lime, magnesia, and clay, and produces the very best quality of wine. There is also an iron-ochre soil, which produces a fine wine of a coarser nature. There is likewise an alluvial soil, and lastly a sandy soil, which produces from five to six butts to the acre; the superior soil not more than three; taking the average, it would give about four butts an acre. On the whole, there would be about 120,000 butts a-year produced in the district. It appears from the evidence of Dr. Gorman, that many years ago Spain shipped her wines to this country the second and third year after the vintage, when the wine had been perfectly fermented, and properly cleared of all vegetable and fermenting matter; so that sherry came into Great Britain in a more natural state than at present. The demand for this wine increasing beyond the supply, recourse was had to the produce of other districts to mix with their wines. If there were a taste for natural wines in England, Spain alone could supply hundreds of thousands of butts of choice wines not yet known in the market. In Spain, as in Portugal, the wine is doctored to suit the English taste. The genuine wine of Xeres is carefully fermented, and in the spring following, the vintage is racked from the lees, brought into the town, and placed in casks in a cellar, where it remains for years. This pure wine never reaches Great Britain, because the exporter confines his operations to the instructions of the English wine-merchant, who transmits an order for twenty or thirty butts of wine to be prepared in a certain way, and to have a particular taste, flavour, and colour. The cellars above-mentioned are each under the care of a captain or head man, who classes the wines, and puts arbitrary marks upon casks, according to their quality. In the course of the year, he frequently inspects the wine, and often reverses his own marks, from a new development of its quality; some casks progressing more rapidly to maturity than others, from their position in the cellar, or from the quantity of natural alcohol or saccharine matter which the wine contains. The arbitrary marks to distinguish the fine qualities are triple, double, and single *Palma*, and so on, running over 10 or 12 numbers. Exporters regret that they are obliged to make a compound article, to suit the artificial taste of the English market.

The quantity of alcohol which all good sherry wines contain is about 12 per cent. The strength of the mixed wine depends upon the quantity of brandy which the exporter thinks it necessary to add. This is sometimes, in the case of inferior wines, as much as 6 or 8 gallons of Catalonian brandy to a butt (108 imperial gallons) of wine. This is more necessary in the case of wines of inferior quality than in others, because such wines contain a large quantity of vegetable matter in solution, and do not usually contain more than 8 or 9 per cent. of natural alcohol. Much of the wine grown in the Xeres district is conveyed into the Bay of Cadiz, and there mixed with inferior wines, and shipped off as sherries. These inferior wines are brought from various parts of Spain, for the express purpose of being mixed with sherries at a place called the Aguada, in Cadiz.

Speaking of *Manzanilla* wine, which appears to derive its name from the Spanish for camomile, Dr. Gorman states that it is produced in the sherry district, in a soil which is a favourable mixture of the alluvial, sandy, and *albariza,* or carbonate of lime, magnesia, and clay. The species of vine planted there is also favourable, producing a wine full of flavour, and which comes in early. It is a wine that admits of no admixture; and though it is of light body—as light looking as water—yet if perfectly fermented, it will endure for thirty years. It is a genuine wine, and has a fragrant aroma, and a kind of sub-bitter taste. It is stated that this wine may

be drunk by those who have organic affections, or great irritability with an inflammatory tendency, with impunity, if not with advantage.

The present consumption of foreign wines in Great Britain is about 6,000,000 gallons per annum, on which a uniform rate of duty of 5*s*. 9*d*. per gallon is paid, with the exception of Cape wine, on which a duty of 2*s*. 8*d*. per gallon is paid. The following table shows the annual average quantities of wine in gallons on which duty was paid, and the yearly average amount received at the different rates of duty, in periods from 1814 to 1849 :—

	1814—1824.		1825—1830.		1831—1839.		1840—1849.		1850.		1851.	
	Duty. *s. d.*	Gallons.	Duty. *s. d.*	Gallons.	Duty. *s. d.*	Gallons.	Duty. *s. d.*	Gallons.	Duty. *s. d.*	Gallons.	Duty. *s. d.*	Gallons.
French	13 9	177,000	7 8	379,000	5 6	315,000	5 9	379,000	5 9	354,000	5 9	365,000
Portugal	9 1¼	2,657,000	4 10	3,185,000	5 6	2,749,000	5 9	2,456,000	5 9	2,719,000	5 9	2,891,000
Spanish	9 1¼	986,000	4 10	1,917,000	5 6	2,296,000	5 9	2,437,000	5 9	2,558,000	5 9	2,587,000
Madeira	9 2½	325,000	4 10	279,000	5 6	143,000	5 9	91,000	5 9	87,000	5 9	82,000
Azores.........	9 1¼	4,000	4 10	5,000	5 6	1,000	5 9	178	5 9	67	5 9	245
Canary	9 1¼	156,000	4 10	132,000	5 6	57,000	5 9	22,000	5 9	20,000	5 9	16,000
Rhenish........	11 3½	22,000	4 10	80,000	5 6	51,000	5 9	54,000	5 9	48,000	5 9	56,000
OTHER SORTS.												
Marsala, &c...	9 1¼	62,000	4 10	175,000	5 6	354,000	5 9	447,000	5 9	457,000	5 9	437,000
Cape............	3 0½	440,000	2 5	627,000	2 9	529,000	2 10½	347,000	2 10½	241,000	2 10½	246,000

1814 to 1824	Duty average	£2,125,050	Number of gallons	4,832,789
1825 to 1830	—	1,613,064	—	6,784,802
1831 to 1839	—	1,700,589	—	6,497,550
1840 to 1849	—	1,746,002	—	6,238,044

It has been proposed to reduce the import duty on wines from 5*s*. 9*d*. to 1*s*. per gallon. Those who support this reduction imagine that a taste for the pure and light wines of the Continent would soon become so general among the middle classes of this country, as to compensate for any loss of revenue which might attend the first reduction of the duty. We do not expect that so desirable a result would be attained. In our cold and uncertain climate, the taste is so common for more potent drinks than the light wines of France and Germany, that the brandied wines of Spain and Portugal must, we think, continue to be favoured. But it is argued that a large section of the middle classes who now consume no wine at all, and those even who are habitual water drinkers, would, if they could procure a pure wine at the low rate of 1*s*. per bottle, drink it habitually. This, however, is a mere assumption, and is not warranted by the fact that such persons, in their rare visits to the Continent, consume and enjoy the light wines of the country; they also enjoy the various strange dishes which are set before them, but they do not on that account, on their return to England, adopt the French or German *cuisine;* and we think it might be doubted whether, if they had the choice, they would exchange their porter and ale, their port, sherry, and grog, for the wines of Bordeaux or of the Rhine.

It is, however, certain that a high rate of duty is disadvantageous to the country which produces, as well as to that which proposes to receive any article of commerce. If wine be the surplus produce of the south of France, and manufactured goods the surplus produce of England, it is of great importance to exchange one for the other as extensively as possible; but this exchange will be limited in proportion as the rates of duty levied by either country are high. In his evidence before the Committee on Wine Duties, Mr. Gassiot reviews the effect of raising or lowering the duty on wine. From the year 1814 to 1824, we had differential high duties, French wine being at 13*s*. 9*d*. per gallon; Rhenish wine, 11*s*. 3*d*.; other wines, 9*s*. 1*d*.; and Cape wine, 3*s*. In 1825, the duties were considerably reduced; French wine being reduced to 7*s*. 3*d*., and all other wines, except Cape, to 4*s*. 10*d*.; the Cape wine was reduced to 2*s*. 5*d*. In 1830 or 1831, the duties were assimilated to 5*s*. 6*d*. on all wines except Cape, which was at 2*s*. 9*d*. In 1839 or 1840, the duty was increased by an *ad valorem* of 5 per cent. It will be seen by reference to the foregoing table, that an increased rate of duty diminished the consumption of wine, while a low rate of duty considerably increased it.

In order that the revenue may not suffer loss by the proposed reduction of duty from 5*s*. 9*d*. to 1*s*. per gallon, it would be necessary that the annual average consumption of 6,000,000 gallons should be increased to 30,000,000 gallons. It is not likely that so large an increase would occur, and should it do so, doubts have been expressed as to the capabilities of the wine-growing countries to supply the increased demand. Those, however, who are well acquainted with the wine-growing districts of France, incline to the opinion that the banks of the Rhone would alone supply it. Mr. Tuke states that from Cette alone we could easily draw 50,000 pipes; from Port Vendres, 10,000 pipes of a wine particularly qualified for this country, and that Marseilles would supply any quantity required. In the neighbourhood of the Rhone, there are vast tracts of land capable of producing fine wines, which are now uncultivated in consequence of the limited demand; and it is stated that if a demand sprang up in this country four hundred times greater than it is now, that demand could be met by increased cultivation.

These remarks apply to ordinary wines of fair quality, but it must be understood that the supply of the finest wines will always be limited. The finest ports are obtained from a comparatively small district of the Douro. The vineyards in the immediate vicinity of Xeres alone produce the finest sherries; the finest clarets are grown in the small district of Médoc, as already noticed; and there is only one small valley in the island of Madeira where the finest malmsey can be produced. The people of England are so accustomed to drink wine under the name of port or sherry, that the attempts to introduce other red wines and white wines as substitutes, under their own proper names, have completely failed. One witness, who has tried the experiment in the case of red wines, says, "Neither *Masdeu*, *Figueira*, nor the red Sicilian wines, however low the price may be, will ever come into competition with genuine port-wine." Large quantities of red wine are, however, introduced and passed off as port. Mr. Tuke says that he has sold red wine from Marseilles, particularly from one soil, under the name of *Bandole*, at 35*s.* per hogshead on board, which has come to this country and has been consumed, and has re-appeared, no doubt, under the name of port, as he has not seen it since it left his hands. Contracts for wine have lately been made by the same gentleman at 4*s.* a dozen, *i. e.* 4*d.* a bottle, (including cases, bottles, and corks,) which wine came to Liverpool, and is described as a fair sample, and wine that would stand any voyage: it was destined for African consumption. It is a common practice, in the docks of the port of London, to introduce red wines from France and elsewhere, to mix them with wine from Oporto, to pay duty on them as "ports," and send them out to the public as such. Thus the comptroller of accounts in the London Docks, on being examined before the Committee of the House of Commons already referred to, admitted that if 1,000 casks of port-wine were exported from Cette to New York, and then brought to London as port-wine, it would be at once mixed with the port-wine of Oporto, and called port. In this way 20,000 casks of wine from Oporto may become 60,000 casks for the use of the consumer. French wines have also been shipped from London to Jersey or Guernsey, and then brought back as port-wines.[1]

The abundance and cheapness of wine in many parts of the Continent are indeed surprising to an Englishman, who obtains a scanty supply at a high rate, and often of bad quality. Fiscal regulations interfere to prevent the overflowing with wine from being a blessing, as it was in the days of old. Many a wine-growing district would gladly exchange its abundance of wine for our manufactured products, could the respective governments only consent to the interchange. Wine that would gladden us is often thrown away or merely given away, from its very abundance. The produce of wine in France alone is estimated at 800,000,000 of gallons per annum, the average value of which is about 7*d.* per gallon. Of this quantity however, according to Lenoir, one-sixth is of good quality, one-sixth passable, one-sixth drinkable, and three-sixths varying from bad to detestable. The bad wines, and the wines of very abundant harvests, are distilled, the quantity amounting to about 110,000,000 gallons. The quantity of wine exported from France to Great Britain is only 400,000 gallons, and the whole of the French exports throughout the world does not exceed 24,000,000 gallons. The home consumption is therefore very large, amounting, in fact, to the consumption of beer in Great Britain, or about 20 gallons per head per annum. In Paris alone, where the wine is subject to an octroi duty, the consumption averages 216 bottles per head per annum of the population.

Considerable changes have taken place in the taste for wine among the educated classes of Great Britain for some years past. Not only is less wine drunk, but, as Mr. Shaw observes, "a decided change for purer and less brandied wine is taking place; the causes of which are—1. The numbers who now visit the Continent; and no one can do so for even a month without finding all our wines, scarcely excepting our claret and other kinds from France, disagreeably heavy and loaded. 2. The fear of every one, with any regard for his character, lest he should appear intoxicated—a great contrast to times not long past. 3. That instead of dining as formerly about five o'clock, and remaining many hours at table, the usual dinner-hour is about half-past six and later. The fact of much more white wine being drunk during dinner, and the abandonment of the habit of sitting for any length of time after it, are showing moreover their effects on the consumption of port. This old custom is peculiar to ourselves, and, like other singularities of individuals and nations, is falling before civilization and

(1) The "Association for the Prevention of Frauds in the Wine and Spirit Trade," attempted in 1851 to put a stop to this practice, as the following memorial will show:—

"To the Honourable the Commissioners of her Majesty's Customs for the Port of London, the Memorial of the Committee of the Wine and Spirit Association, London, showeth, that it has come to the knowledge of your memorialists that wine of various descriptions, viz. Spanish red wine, French, Teneriffe, Marsala, with sometimes a small quantity of port wine, and in some instances none, have been blended together in the public warehouses in London, and in foreign parts, shipped to Guernsey and other places, and immediately imported as port wine. Your memorialists have no desire to interfere with the legitimate freedom of trade, nor to deprive the public of the enjoyment of such mixtures if they require them; but they have always considered it their duty, both to their constituents and the public, to prevent by all means in their power every description of fraud, and are convinced that in so doing they will receive the support of your Honourable Board. The blending having, as they are informed, been done with your sanction, they do not presume to make any comment upon it; but they are perfectly certain that the use made of it cannot have received your approbation, and they beg leave, therefore, respectfully to suggest that, for the purpose of preventing the repetition of such use, all wine not imported direct from the place of its growth, shall be admitted to entry only as 'red' or 'white' wine, as the case may be, but not allowed to be described as the produce of any particular country, unless accompanied with a satisfactory certificate of origin. And your memorialists will every pray, &c."

In answer to this memorial, it was stated by the Custom-house authorities that the plan proposed would not prevent the fraud, but only render it a little more difficult, "as the wine would still be mixed at Guernsey or Hamburgh, and imported as at present under the denomination of Port or any other name which it might serve the importer to give it."

the influence produced by greater intercourse with others. Another cause still, which bears both upon the quantity and quality of the wine consumed, arises from the comparatively little party and political animosity which now exists, but which formerly led to much drinking; and a great change is also attributable to a higher tone of manners and of conversation, making discussions on what we eat and drink comparatively rare. Neither would it be fair to those excellent advocates of abstinence from all intoxicating liquors, to omit alluding to the beneficial effect of their labours.

"There is no country in the world where drunkenness, and the crimes necessarily arising from it, prevail to any such extent as among ourselves; for, indeed, the consumption of spirits is nearly a gallon yearly for every man, woman, and child, which, independent of large quantities illicitly made and smuggled, is four times the quantity and five times the revenue from wine. It would not be difficult to show the terrible evils and expenses which this curse of our country entails, but it is not by increasing the difficulty of procuring spirits that the evil can be remedied. The true method is to place within the reach of all a wholesome, cheering beverage, which wine is in its pure unadulterated state. And let me here remark, that in no work descriptive of the habits of our own or of other countries, before the beginning of the last century, do we find allusion to the use of spirits; neither among their numerous strange compounds do the ancients appear to have drunk them. It will invariably be found that whenever the choice and taste have not been fettered and forced, as has been the case with us, a pure unsophisticated quality is preferred, even in the northern latitudes, to the strong heavy kinds in use here. Even in the comparatively cold climates of Scotland and Ireland, claret was the wine invariably drunk, and so it continued until a much later period than in England, as in the former countries the facilities for smuggling enabled the importation of cargoes thereof long after it had been suppressed in England. Here also, however, little else than French wines were used, until, owing to the violent feelings roused against France about the period of our revolution in 1688, the duty on her wines was raised, during the thirty years from 1677 to 1707, 1,600 per cent. (from 4*d.* to 5*s.* 3*d.* per gallon), continuing for many years at 13*s.*, and being actually raised in 1813 to 19*s.* 8*d.* per gallon, or 39*s.* 4*d.* per dozen. The consequence has been that excepting in 1825, when the duty was lowered from 13*s.* 9*d.* to 7*s.* 3*d.* per gallon, the consumption never exceeded 500,000 gallons, having been previously less; and even last year, including all the cheap red wines and champagne, it was only 447,559 gallons, about a fourteenth part of the whole consumption."

Mr. Shaw states that he knows a tavern out of the barriers of Paris, where more than half that quantity is drawn off yearly at 3*d.* per bottle, and though frequented by the lowest classes, a drunken person is rarely seen. By reducing the rate of duty to 1*s.* per gallon, it will still be from 50 to 100 per cent. on much that would be imported, and a higher rate would prevent that full expansion of the trade which cheapness alone can produce. "Another most important benefit that would be derived from this rate is the very large saving which might then be effected in the customs, since wine being now the only article which receives drawback on exportation after leaving the custody of the revenue-officers, this might also be abolished if the duty were only 1*s.* per gallon, or 2*s.* per dozen, and the Customs system be thereby much simplified, and numerous frauds prevented. In reducing the duty, there ought to be no distinction of countries; all should be put upon the same footing, whether they act reciprocally towards us or not. Our business is to let every country send us what we consider best and cheapest; and if they would give us their wines or other things for nothing, it would be all the better for us. The most difficult point connected with this question is the return on stocks in hand. Taking the amount of duty-paid stock in wine-merchants' cellars as equal to the quantities cleared from bond during three years, the amount of duty invested is about 5,500,000*l.*, and supposing the rate to be lowered to 1*s.* per gallon, the claim for return, or repayments for the difference, would be about 4,600,000*l.*, but this is perhaps too high an estimate. It is probably no exaggeration to assert, that nine out of every ten wine merchants are opposed to a considerable reduction of duty, believing it would lower profits and prices, and open the trade to every one, making wine as commonly sold as tea, sugar, or beer." It appears from official documents that from 1791 to 1800, a population of 14,500,000 averaged 6,513,019 gallons, yielding 1,412,820*l.*; while during the last year 27,309,346 consumed 6,280,587 gallons, producing 1,777,259*l.* As, however, hard drinking was the custom and fashion of the former period, we shall arrive at a more correct basis by taking the means of expenditure, rather than the number of the people. We have no means of estimating the value of accumulated property when the tax upon incomes was imposed in 1812; but this was rated at 21,000,000*l.*, and is calculated to have been 15,000,000*l.* in 1800, and last year the amount laid upon the same sources was nearly 60,000,000*l.* Taking then 6,513,019 gallons as the consumption of 1800, at which time, with the exception of French, which did not then form 2 per cent. of the whole, the duty was very similar to the present rate, it follows that if the consumption had continued in the same ratio to the means of expenditure, the annual quantity, even at the present high rate of duty, would now be 26,052,076 gallons, giving 7,493,620*l.* of revenue; and this quantity, large as it seems, (being a great contrast to our present one bottle and and a fraction,) would be less than six bottles yearly to each person; while, in highly taxed Paris, the proportion is 216 bottles. If we had wine as cheap as the Parisians, although it might be long before we should average 216 bottles, it may surely be assumed that during the very first year of cheapness we should reach twelve bottles, or two gallons, which,

with our present population, would be 54,618,692 gallons, producing, at 1*s.* per gallon, a revenue of 2,730,934*l.*, being an increase of 953,675*l.* Excluding port, the price of which, as I have shown, is artificially kept up, I have no hesitation in asserting that the present rate of 5*s.* 9*d.* is a higher per centage on the value of the great proportion of wines now taken out of bond, than 8*s.* would have been twenty years ago; for in order to counteract as much as possible the enormous duty, and to meet the demand for 'cheapness' experienced in every other article on which the duty has been abolished, or greatly diminished, recourse is had to very inferior descriptions, making the duty very often 200 per cent. on the cost."[1]

An account of the quantity of wine retained for home consumption in the United Kingdom, in each of the years 1849, 1850, 1851:—

Wines.	1849.	1850.	1851.
	Gallons.	Gallons.	Gallons.
Cape	241,845	246,132	234,672
French	331,690	340,748	447,556
Canary	19,868	15,995	15,928
Fayal	67	246	131
Madeira	71,097	70,360	71,025
Portugal	2,648,242	2,814,970	2,524,775
Rhenish	46,405	54,668	58,957
Spanish	2,448,107	2,469,638	2,533,384
Unenumerated	444,541	425,056	394,225
All Sorts	6,251,862	6,437,222	6,280,653

The following table gives the statistics of wine for the United Kingdom, for the year ending January 5th, 1853.

Wines.	Quantities Imported.	Upon which duty has been paid.	Exported.	Retained for home consumption.
	Gallons.	Gallons.	Gallons.	Gallons.
Cape	127,952	242,805	4,054	242.619
French	575.280	503,919	169,595	475,948
Portugal	2,120,716	2,567,774	384,612	2,489,350
Spanish	3,181,835	2,738,089	865,567	2,606,857
Madeira	141,317	82,064	93,075	69,730
Rhenish	70,297	60,711	12,238	58,533
Canary	86,819	16,033	86,220	14,877
Fayal	56	396	89	397
Silician and other sorts	489,032	402,888	145,261	387,750
Mixed in bond	—	—	41,306	—
TOTAL	6,793,304	6,614,679	1,802,017	6,346,061

Many excellent works have been published on the subject of Wine, of which the following are a few:—Henderson, "History of Ancient and Modern Wines," 4to, London, 1824; M'Culloch, "On Wine;" Cyrus Redding, "History and Description of Modern Wines," 3d Edition, 8vo, London, 1850; Paguierre, "Wines of Bordeaux," 12mo, Edinburgh, 1828; Jullien, "Topographie de tous les Vignobles connus," 3d Edition, 1832; Bronner, "Die Deutschen Schaumweine;" also, "Weinbau in Süd-Deutschland;" and "Weinbau in Frankreich."

WIRE. The malleability of certain metals was probably discovered before their ductility, for it is evidently a simpler process to beat out a metal into a thin sheet, than to form it into a rod, and gradually extend its length by passing it through the holes of a plate of metal harder than itself. It has been suggested by Beckmann, that wire was first formed by cutting up sheets of metal into thin strips, a process actually followed in making the sacerdotal dress of Aaron, as we read in Exodus xxxix. 3, "And they did beat the gold into thin plates, and cut it into wires, to work it in the blue, and in the purple, and in the scarlet, and in the fine linen, with cunning work." Wirework is but rarely mentioned in the writings of the ancients, and in the few cases which do occur the metal appears to have been wrought on the anvil. In the more modern works on Technology, no mention is made of the *draw-plate.* In the History of Augsburg, of the date 1351, and in that of Nuremburg, 1360, the artists who fabricated wire by means of the hammer are called wire-smiths; but as the term wire-drawer (*drahtzieher*) also occurs in these works, it is evident that the draw-plate had been invented, but had not entirely superseded the ancient method. In France, the invention is ascribed to one Richard Archal, and iron-wire is called in that country *fil d'Archal,* and also *fil de Richard.* It is stated that wire was manufactured by hand in England until the year 1565, when one Christopher Schultz, a Saxon, in company with other foreigners came to this country, under the permission granted by Queen Elizabeth to strangers, to dig for metallic ores, and introduced the drawing-plate. Previous to this, the supply of iron-wire, together with the combs employed by the wool-combers, was chiefly obtained from abroad. In the reign of Charles I. it is stated in a proclamation that "iron-wire is a manufacture long practised in the realm, whereby many thousands of our subjects have long been employed; and that English wire is made of the toughest and best Osmond iron, a native commodity of this kingdom, and is much better than what comes from foreign parts, especially for making wool-cards, without which no good cloth can be made. And whereas complaints have been made by the wire-drawers of this kingdom, that by reason of the great quantities of foreign iron-wire lately imported, our said subjects cannot be set on work; therefore we prohibit the importation of foreign iron-wire, and wool-cards made thereof, as also hooks and eyes, and other manufactures made of foreign wire. Neither shall any translate and trim up any old wool-cards, nor sell the same at home or abroad." The Forest of Dean, which supplied good charcoal iron, was long the seat of the wire-drawing trade; but in the 17th century, it seems to have followed the woollen cloth manufacture into Yorkshire. Barnsley and its neighbourhood were long celebrated for the manufacture of wool-cards; but at present wire-drawing is carried on throughout the manufacturing districts, Birmingham having perhaps the largest share in the trade.

Previous to the introduction of grooved rollers [see IRON, Fig. 1240], the rods of iron intended for wire-drawing were hammered out to the required size. The best iron was used for the purpose, and was sold in rods of about the thickness of

(1) Letter from Mr. Thomas George Shaw to the Editor of the *Times*, April 22, 1852, handed in in his evidence before the Parliamentary Committee.

the little finger, made up into bundles, and called *usteom* or *esteom* iron, or as in the proclamation of Charles I., *Osmund* or *Orsmund* iron. A further reduction in the size of the rods was effected by *ripping* or *rumpling*, in a drawing machine, in which, according to Beckmann's description, the axle, by means of a lever, moves a pair of pincers, that open as they fall against the drawing-plate, lay hold of the wire, which is guided through a hole in the plates, shut as they are drawn back, and in that manner pull the wire along with them. In the modern process the rods are prepared for the wire-drawer at the rolling-mill, or for some metals by casting, and are generally about the eighth of an inch in diameter; they are sold to the wire-drawer in coils. Cast-steel wire for making needles is still commonly tilted to about a quarter of an inch square, and afterwards rounded on the anvil, previously to being passed through the drawing-plate.

The coils of rods, as received by the wire-drawer, are covered with a scale of oxide which must be carefully removed, for which purpose the coils are put into a large revolving cylinder containing coarse gravel and water, the effect of the gravel being to loosen the oxide, and of the water to remove it. In order to reduce, or draw out the rod into a great length of wire, a number of similar operations are performed upon it so as to effect the object gradually. The rod is first dragged forcibly through a hole in the drawplate of somewhat less diameter than itself, and as the metal of the drawplate is harder than that of the rod, it necessarily happens that the latter gives way and becomes extended in length, or, as Mr. Holtzapffel expresses it, "the substance of the metal is partly kept back, as in a wave, by a narrow ridge within the draw-plate, acting as a burnisher." This lengthened wire is again passed through a hole smaller than itself, and thus again elongated. The process is repeated 10, 20, or 30 times through holes gradually diminishing in diameter. The draw-plate should be formed of the best cast-steel, about 6 inches in length and 1½ inch in diameter, and of a roundish form, with the exception of one flat face. The holes through which the wire is drawn, are formed by punching the flat side of the plate while red-hot, several punches gradually diminishing in size being employed for each hole, so as to make it of a tapering form; or the holes are sometimes "ground out from both sides upon the same brass cone or grinder, the sides of which vary in obliquity from 10 to 30 degrees, according to the metal to be drawn; for the sake of strength, the ridge is mostly nearer to the side on which the metal enters, and the sharp edge is also removed by wriggling the plate upon the grinder in order to round the inside, or in any other manner." To prevent the fracture of the draw-plate, it is usual to support it against a strong perforated wrought-iron plate.

Fig. 2374 represents a wire-drawer's bench, containing the drawing-plate, fixed in an upright position, and a cylinder or *drawing-block*, the motion of which draws the wire through the plate, and winds it upon its rim. Motion is imparted to this block by means of a horizontal shaft of iron, revolving either by steam or water power. Attached to this shaft are a number of mitre or bevel wheels, which drive a number of

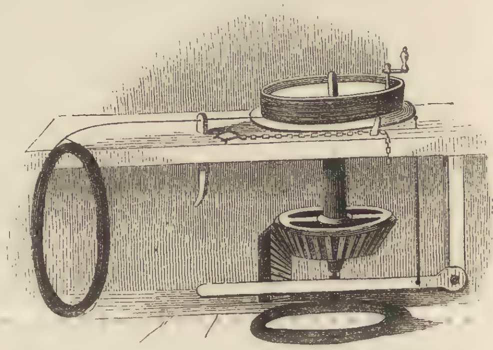


Fig. 2374. WIRE-DRAWER'S BENCH.

upright shafts, each of which contains a drawing-block. Each block can be instantly stopped by detaching it from the upright, by means of a foot-lever. A cross at the top of the upright fits into a corresponding cavity at the bottom of the block, so that when the lever is pressed by the foot, the block is simply lifted off the cross, and is at rest. At the commencement of the operation, the workman makes one end of the coil hot, and hammers it to a point on the anvil, so as to make it pass through a hole of the draw-plate. The end of the wire is then grasped by a pair of tongs or forceps attached to a chain, rope, toothed-rack, or screw, by which the wire is drawn through the draw-plate by rectilinear motion, until of sufficient length to coil round the drawing-block, which is furnished with a small vice for the purpose of grasping the end firmly. The forceps or nippers are similar to carpenters' pincers or pliers, and the handles diverge at an angle; in some cases they are closed by a ring at the end of a strap or chain, which slides down the handles. The workman then lowers the block upon the upright shaft, when the block begins to revolve and to draw the wire through the plate, and wind it in coils round itself. When all the wire is thus coiled, the block is raised, the wire removed, and the workman proceeds to draw another piece. By varying the size of the mitre or bevel wheels, the blocks are made to revolve at different rates of speed, so that the thick and strong wires may move slowly, and the speed be increased as the wire is more and more drawn out. There are usually four rows of blocks revolving at different speeds, the swiftest motion reducing the wire to about No. 19 or 20 on the wire-gage. Should the wire require further reduction, it is passed to the *card-wire-drawers* or *fine wire-drawers* (who often carry on a distinct trade), and they reduce it to the finest numbers, in some cases as fine as No. 40, which, when formed into very fine wire gauze, will have 120 wires each way in an inch, thus making 14,400 wires, and as many spaces, in the square inch.

After passing the wire a few times through the draw-plate, it is not only extended in length, but its fibres become so condensed and hardened, that it is impossible to repeat the operation without annealing the wire. For this purpose it is placed in coils in cylindrical kilns of iron plate, each about 4 feet diameter, and 10 feet deep, with an outer casing of fire-brick. Each kiln contains from 20 to 30 cwt. of wire, the largest coils being put in first, and the smaller ones within them. The cylinder is carefully closed, and a fire lighted below, so as to heat the cylinder to redness. This being attained, the fire is allowed to go out, and the cylinder and wire cool gradually; 24 hours being occupied in the whole process of heating and cooling. In the production of very fine wire, the annealing is repeated 6 or 8 times, a smaller number being sufficient for the stouter kinds, and charcoal iron requires less annealing than coal or coke smelted iron. The process of annealing produces a scale or oxide on the surface of the wire, which must be removed by pickling in dilute sulphuric or other acid, for if this scale were allowed to remain, it would rapidly corrode the draw-plate. The card wire-drawers draw the wire from a reel contained in a tub of starch-water or stale beer grounds, the effect of which is to impart a clear, bright colour to the wire. It is however not uncommon to use some lubricating substance, to enable the wire to pass more readily through the draw-plate; starch-water and beer-grounds act in this way, and for gold and silver, wax is commonly used. In the course of wire-drawing the holes have a tendency to become enlarged, a defect which the workman corrects by closing them with blows of a pointed hammer or punch around the hole. The gage used for determining the size of wire is noticed fully under GAGE—GAGING.

The various metals used in wire-drawing are stated in the order of their ductility under METAL. The so-called gold wire of Lyons is formed by exposing a rod of copper at a red heat, to the vapour of zinc, whereby it is externally converted into brass. Platinum wire may be formed of extreme tenuity, by first encasing a platinum wire with silver, and drawing out the compound wire as far as it can be done without breaking, and then steeping the wire in nitric acid, which dissolves off the silver, and leaves the platinum untouched. See PLATINUM.

Wire is mostly cylindrical in form, but draw-plates are also made oval, half-round, square, triangular, and of complex sections, for the production of corresponding wires by the methods above described. Pinion wire, for clocks and watches, is formed by drawing. Copper is also drawn into a variety of forms for fixing into blocks used in calico printing; an endless variety of patterns may be produced in this way; and when the pattern is composed, the surfaces of the wires are filed smooth, and printed from after the manner of printers' types. [See CALICO PRINTING, Fig. 407.] Music-type is also formed of detached wires and slips of copper fixed in a block, which is printed from. The edging of silver or gold boxes is formed by drawing between a pair of swage blocks or dies of the required section, fitted into a frame or cramp, with a side screw, so that the metal may be gradually reduced by one pair of swage bits. Window lead is formed in the *glazier's vice*, which combines the two principles of drawing and rolling. The indentations in the lead for the reception of the glass, are formed by two narrow rollers with roughened edges, which indent the bottom of the grooves; while the flattened sides of the lead are formed by the usual method of drawing. Rubies and other gems are drilled with holes conical on both sides, and thus form draw-plates, for making the slender silver-gilt and silver wires used in the manufacture of gold and silver lace. The wires are afterwards flattened, wound spirally upon silk, and then woven into lace. Ruby holes are used for forming the blacklead of ever-pointed pencils. The rubies are chamfered from one side only, and the lead is pushed through from the small side. The wire for pendulum springs of chronometers is sometimes drawn through a pair of flat rubies with rounded edges. Tubes for telescopes, &c. are drawn upon a mandrel, as described under TUBES AND PIPES. In this case, the draw-plate, Fig. 2182, is made with three cones instead of two, the central cone being just equal to the wave, or the quantity of the metal is reduced.

As the wire for ordinary purposes is sold in coils, it requires to be straightened for use. For the softer wires, such as the copper wire used in bell-hanging, and the iron binding-wire used in soldering, it is sufficient to fix one end and pull the other end with a pair of pliers. Short pieces may be straightened by being rolled between two boards. Hard-drawn and unannealed wires, such as those used for making pins, bird-cages, &c., are straightened, and the spring is taken out of them by drawing them through a *riddle* consisting of a board, in which are fixed pins, sloping in opposite directions, so as to force the wire into a slightly zigzag or serpentine course, at the same time keeping it close to the board. The positions of the pins require to be corrected with the hammer for wires of different diameters. In pulling the wire through, it must not be allowed to lean sensibly against the last two pins, or it will be curved instead of straightened.

WOAD (*Isatis tinctoria*), a plant used at a very early period for the purposes of dyeing. Cæsar states that the ancient Britons were accustomed to stain their bodies with this substance. Woad yields a substantive blue colour, of different shades, and very durable; and it is also useful in dyeing and fixing other colours. It was in extensive use until the introduction of indigo, which affords a superior colour, but it is still used in conjunction therewith [see INDIGO]. Woad is extensively grown in many parts of Europe: in the South of France it is distinguished by the name of *pastel*; but it is stated that the use of indigo has led to negligence in the cultivation of woad; so that it is inferior now to what it was formerly. Woad is a biennial plant; it has a large

woody root, which penetrates to some depth, and a stem from about 3 to 4 feet high, and about ½ inch in diameter, forming several branches, covered with light-green leaves attached close to the stalk: the leaves afford the dye colour; they are about 12 inches long, 6 inches broad at the widest part, and terminate in an obtuse point. The plant bears a small yellow flower, and the seeds come to maturity in September. It thrives best in a friable loamy soil, and furnishes three or four crops in the course of the year, the first crop when the stems begin to turn yellow, and the flowers are about to appear; the other crops are gathered at intervals of about six weeks. The average produce per acre is about one ton; in very favourable seasons one ton and a half may be obtained. It is an exhausting crop to the land. The best woad is obtained at the first two gatherings. The plant is cut down with a scythe, collected, and washed in running water. The leaves are then stripped off and dried in the sun as rapidly as possible. It is next immediately ground in a mill into a smooth paste. The liability of woad to blacken and putrefy requires celerity in all the operations. The paste is formed into heaps, made smooth, and sheltered from the rain: over these heaps a blackish crust forms, which, if it cracks, is immediately closed, or the woad becomes worm-eaten and loses its strength. The heaps are opened in a fortnight, and the crust is mixed with the interior portions. The paste is formed in moulds into balls, and dried upon hurdles: if dried in the sun they become covered with a black crust, and if in the shade, with a yellow one. The former is preferred by the dealers. Good balls are heavy, and show a violet colour within on being rubbed. In using these balls for dyeing, they are beaten into a coarse powder, moistened with water, and being collected in heaps, fermentation takes place: this is carried on for 12 or more days, until at length, according to the experience of the operator, the woad is fit for the dyer. A powder is produced in this way which furnishes shades of a brownish colour when mixed with water, spirits of wine, or alkaline solutions: it forms a green stain by friction on paper. If the powder be diluted with boiling water, and left to stand some hours in a close vessel, having $\frac{1}{20}$th of newly-slacked lime added, with stirring under a gentle heat, a fresh fermentation occurs, a blue froth rises, and the liquor, though appearing reddish, yet dyes woollen of a green colour, which, like that from indigo, changes to blue on being exposed to the air. If the plant be treated like the indigo plant, indigo will be afforded, but in smaller quantity. Woad greatly improves by age.

WOLFRAM. See TUNGSTEN—TIN—INTRODUCTORY ESSAY, p. xcvi.

WOOD. The most important application of wood is in the building and repairing of houses and ships, and in the construction of machinery. For this purpose the larger trees, which come under the denomination of *timber*, are chiefly employed. *Oak*, *ash*, and *elm*, of the age of twenty years and upwards, are the principal timber trees of England, although other trees, such as *beech*, *cherry*, *aspen*, *willow*, *horsechestnut*, *lime*, *yew*, &c., are commonly ranked as timber trees. Some centuries ago, the woods and forests of Great Britain supplied the home demand for timber, but in the 16th century the supply began to fail, in consequence of the large quantity consumed in the smelting of iron ore [see IRON]. Various acts of Parliament were passed for limiting the consumption, and obtaining a supply from abroad, in the form of staves for casks and other forms. It was even attempted to transfer the smelting of iron to the North American colonies, in order to prevent the waste of wood at home; but this measure was arrested by the application of pit-coal to the purpose, as noticed under IRON, and a further extensive economy was made when the prejudices against pit-coal as a domestic fuel were overcome. [See WARMING AND VENTILATION.] Increasing population, however, led to an extensive demand on other countries for the supply of timber, which was met chiefly by vast pine forests on the shores of the Baltic and northern Europe, and also from Canada. Timber from the latter country, however, was soon found to be inferior in strength and durability to that of the north of Europe, and fell into disesteem among ship-builders; hence arose the practice of introducing the words "Memel fir" in specifications for building.

The preservation of growing timber is an art of considerable importance, and can only be said to be cultivated in countries where timber is comparatively scarce. When timber was abundant in Great Britain, the right of lopping trees of their dead wood for the purposes of fuel was not difficult to obtain. It is stated that many of the fine old oaks in Windsor Forest show signs of unskilful lopping and the want of discrimination between living and dead wood. Oak trees are commonly found in stiff clay soils, and the accumulation of water at their roots in such a retentive soil is apt to lead to premature decay, hence the necessity of a judicious system of draining. Oaks which spring up from falling acorns, and beech from the mast which lies in the woods, produce finer and more vigorous trees than those transplanted from a nursery. Cattle should be excluded from forests, on account of the mischief they do to the underwood. The underwood is almost as valuable as the timber itself, for it may be cut down every tenth year. It is a common practice to fell such timber trees as begin to show decay at the top, at the time of cutting the coppice wood, but it would evidently be preferable to fell them when they have ceased to increase in size by age. Should a tree not increase above two cubic feet per annum in size, it should be felled; but it may happen that a tree may be greatly improved in value by felling some of the neighbouring trees which obstruct its growth. The practice of thinning out plantations is of importance not only as affording a supply of wood, but, by admitting an increased supply of air and light to the remaining trees, their growth is greatly promoted. Oaks are said to increase in size most rapidly when about thirty years old. Forest trees are often planted on soil that is unfit for other purposes, and by the annual fall of leaves they accumu-

late in time a certain depth of soil. Oaks are sometimes planted in hedge-rows, and thrive well, but they greatly injure the adjacent lands, not only by their shade, but by their roots, which spread to a considerable distance in search of pasture, and appropriate much of the manure which is intended for the field.

The transplanting of forest trees, when they have attained their full growth, was long considered an impracticable thing. Many plans had been tried without success, and the source of failure appears to have been the mutilations to which the tree was exposed in the operation. The method adopted by Sir Henry Steuart is successful on account of the great care bestowed in taking up and removing the tree. The ground is carefully picked and dug at a considerable distance from the tree, to find the extreme points of the rootlets. This being done, a deep trench is cut round the tree, and the bank in which the roots lie is undermined, and the rootlets are extricated, to the amount of thousands and even millions. These, with the larger roots, are turned aside or bundled up to make room for the workmen, but all carefully preserved. The tree is then lashed to the transplanting machine, which consists of a long pole attached at right angles to a bar mounted on a pair of wheels. The machine being brought up to the tree, the pole is lashed to the trunk in the first instance in a vertical position: it is then, with the assistance of a horse and men, brought with the tree into a horizontal one, and in this condition the whole tree, root and branches entire, is wheeled away to the pit intended for its reception, and which has been previously carefully prepared, and manured if necessary. A hole in the centre of the pit is specially prepared for the tap roots, and care is taken that while these and the horizontal roots are set deep enough in the pit to have sufficient cover of earth, yet that they should not be buried so deep as to lose the necessary amount of air and moisture. The pit for the reception of trees 30 feet high is about 18 feet in diameter. The tree being brought on the machine to the precise spot intended, the cords which confine the top are first unloosed, and the branches allowed to spread out in the natural manner: two ropes are fixed to the top, transversely to each other, to steady the tree when placed erect: the roots are arranged so as not to be broken by the weight of the descending mass, and on a given signal, the men who are seated near the extremity of the pole, or among the branches, to balance the machine, quit their positions, and the tree rises to a vertical position. The tree is then nicely adjusted, the transverse ropes are stretched to their utmost extent, and the proper depth being regulated, the workmen hold aside the upper roots while they pour in the finest mould to the under-bed of roots, and make of this mould a bank sloping outwards, which is firmly trodden down, and pushed into every hollow and vacancy with a small blunt stake. This forms a nucleus or retaining bank quite clear of the great body of roots and fibres. This method of giving stability to the tree before any cover whatever is laid upon the upper roots is one of the great advantages of this system, and absolutely necessary to success. The roots, which are often from 12 to 14 feet long, are next disentangled and stretched, or, as it were, *combed out* in the most regular manner over this bank of mould, which forms an inclined plane for their reception, and, if well prepared, the best possible soil for their growth. The different layers of roots are thus gradually embedded in mould. If this plan has been carefully carried out, no props are required. The surface soil is rammed down, and sown with grass, or the turf is restored. During the first few years rakings and top-dressings may be occasionally applied round the tree, and will prove a great stimulus to growth.

It may be desirable that the tree be planted in the same position relatively to the points of the compass, as before. But in the case of trees near the coast, or in exposed situations where the action of the wind has made the growth of the tree irregular, a directly opposite course may be pursued. Almost all trees are unequally balanced, and show in their tops more or less of a 'weather side.' This is often a deformity, especially on the western coast. It proceeds from the tendency to throw out longer and stouter branches on the lee side, and shorter and closer branches and spray on that from which the blast assails them. Wherever the action of the air is greatest there the greatest evolution of buds appears, and the thickest but weakest growth of boughs and spray takes place. This difference is so remarkable, that any one conversant with wood, can at once point out an old tree (especially a sycamore) that has been more, and one that has been less exposed, at the distance of two or three hundred yards; and in winter, when there is no foliage to conceal the difference in the ramification, the thing is more striking. Hence it is one of the many improvements effected by Sir Henry Steuart's method, to bring this decided tendency to elongation of the boughs on the lee side to act on the windward or deficient side; or, in other words, the longest branches must be brought to face the stormy quarter.[1]

The proper time for the felling of trees is that in which the largest quantity of hard and durable wood can be obtained as free from sap as possible. It is a common fault to fell trees before they have attained their maturity. If suffered to complete their growth they would have the heartwood of equal weight and strength throughout, whereas in those cut down prematurely, the centre wood alone possesses this requisite, the outer concentric rings being considerably softer. Such timber may be said to decrease in hardness and strength in arithmetical proportion as it approaches the sap-wood. Timber is felled during the cold months, when the natural juices are most inactive and the tree is in a measure dormant. But before the timber can be used, the juices must be got rid of from the capillary vessels, or the wood will remain moist or green for a considerable period, and the planks

(1) "The Planter's Guide," 2d edition, 8vo. London, 1828.

formed from it will, in a confined situation, become stained, and then subject to decay or dry rot: these effects are prevented by free exposure to dry air. It is usual in the royal dock-yards to cut out the timbers for ships of the required shape and dimensions about a year before they are framed together, and the skeleton frame is usually left another year to complete the seasoning. "Other mischiefs almost as fatal as decay also occur to unseasoned woods; round blocks, cut out of the entire circular stem of green wood, or the same pieces divided into quarterings, split in the direction of the medullary rays, or radially; also, though less frequently, upon the annual rings. Such of the round blocks as consist of the entire section contract pretty equally, and nearly retain their circular form, but those from the quarterings become oval, from their unequal shrinking. In general, woods do not alter in any material degree in respect to length. Boards and flat pieces contract, however, in width; they warp and twist, and when they are fitted as panels into loose grooves, they shrink away from that edge which happens to be the most slightly held; but when restrained by nails, mortises, or other unyielding attachments, which do not allow them the power of contraction, they split with irresistible force, and the materials and labour thus improperly employed will render no useful service." The natural juices of the tree must be got rid of by seasoning in order that the wood may become dry and hard. After the tree has been lopped, barked, and roughly squared, it is left for some time exposed to the weather, and may be soaked in fresh running water (as some think) with advantage, or boiled or steamed. This dilutes and washes out the juices, and the water more readily evaporates from the wood at a subsequent period; and the colour of white woods is said to be improved thereby. In this way fir timber, on its arrival at the port of London, is commonly formed into floats on the Thames, and allowed to remain for some time. When removed from the water, it is left to dry thoroughly before it is taken to the pit to be sawn: usually it is blocked up from the ground so as to have a free circulation of air; and if it be cut into boards, they should be piled one on the other with fillets of wood between them, or laid in a triangular form, with their ends alternating so as to allow the air to have free access to them. Thin pieces will be seasoned in about a year, but thick wood requires two or three years before it is removed into the house to complete the drying. The warm air of a stove-heated room will then act upon it with benefit. In the stacking of timber for the purpose of seasoning, the pile should be so far raised from the ground as to allow the air to circulate below, as well as around and through it; and if not sheltered from the rain, care should be taken to prevent the wet from lodging in any part. It is now usual in our dockyards to have elevated supports of iron or of stone for the stacking of timber, and ships are now built under covered sheds. The drying of timber should be gradual, for if rapid, it suffers a loss in toughness as well as in pliability: the pores at and near the surface become contracted, and prevent the interior moisture from escaping. Plans for the more rapid drying of timber by means of kilns have, however, been tried, as in Price's patent, in which timber destined for building purposes is placed in a room, into the lower part of which hot and dry air is introduced, and this, charged with the moisture of the timber, is allowed to escape at the upper part. By this plan timber can be seasoned in one-third of the time required in the open air. Oak loses nearly two-fifths of its weight by proper seasoning. The timber should be dry before it is cut into planks, or they will be liable to warp and shrink.

The presence of air, light, and moisture seems to be necessary to the re-vegetation of timber or the growth of that fungus which leads to its destruction. Mr. Fincham of her Majesty's dockyard bored a hole in one of the timbers of an old ship built of oak, the wood being sound, and in 24 hours the admission of air caused the hole to be lined with a white mouldiness due to the growth of a peculiar fungus, which some time after became so compact as to admit of being withdrawn like a stick. Cracks or splits in timber would therefore predispose it to decay in damp situations by admitting the air. There are great differences in woods as to their power of resisting decay; some perish in a year or two, others are sound and even fragrant for centuries. Teak has been found to last six or seven times as long as oak when used in greenhouses, as boxes for growing plants, the latter wood not existing more than two or three years; but the moist atmosphere, light and heat of a greenhouse form a severe trial for any wood.

Organic matter, such as timber or dead wood, which contains nitrogen, is readily acted upon by moisture and varying degrees of temperature. For the nitrogen, not having any strong affinity for the other elements of the wood, facilitates decomposition or decay, and when this has once commenced, the germs of cryptogamous plants, which had probably been deposited in the living structure by the circulating sap, become rapidly developed, and powerfully assist the action of the other causes of *eremacausis* or slow decay. The fungus, which is chiefly associated with what is called *dry rot*, is known to botanists as the *Merulius lachrymans;* it insinuates itself between the woody fibres, spreads rapidly, and soon leads to the destruction of the wood. These microscopic plants do not grow in situations exposed to currents of dry air, light, and warmth, agents which are advantageously employed in the seasoning and subsequent preservation of wood. The preservation of the surface by means of paints is valuable only when the seasoning has been perfect; for, if applied without this condition, paint acts with mischievous effect in preventing the escape of the natural juices. Many plans, however, have been proposed for the preservation of timber by impregnating it with the solutions of certain metallic salts. The process of *Kyanizing* (patented by Mr. Kyan in 1832) consists in steeping the wood in a solution of bichloride of mercury or corrosive sublimate. It was supposed that the preservative effect was due to the decomposition of the salt ($HgCl_2$) on coming in

Timber Depôt near Quebec

contact with the albumen of the wood, whereby one equivalent of chlorine was evolved, and the salt, now converted into protochloride of mercury, or calomel (HgCl), formed an insoluble compound with the albumen, and prevented, or at least greatly checked its tendency to decomposition. Liebig is of opinion that the corrosive sublimate combines, not with the albumen, but with the lignin or woody fibre. However this may be, a portion at least of the corrosive sublimate must escape decomposition and even combination, for it has been detected by chemical tests to a depth of $\frac{1}{8}$th to $\frac{1}{4}$th of an inch in various woods, and by electrical tests even deeper: it is said to penetrate fir to a less depth than other woods. Kyanized wood has less specific weight and flexibility than ordinary timber, but it is more brittle.

The success of Mr. Kyan's process has been disputed, and this has led to the employment of other solutions. Sir William Burnet has put forward the claims of chloride of zinc as a preserving agent, not only for timber, but also (as with Kyan's process) for canvas, cordage, &c. Oil of tar, and other bituminous matters containing kreosote; a crude solution of acetate of iron, commonly called pyrolignite of iron, with kreosote in solution; and gas-tar free from ammonia, have all been proposed for the preservation of timber, as in Mr. J. Bethell's process. It is stated that wood, preserved by exposure to the vapour of kreosote, becomes so hard as to be worked with difficulty. The importance of oil as a preservative of timber has long been known. The timber of whalers and other ships engaged in the oil trade last much longer, and are less subject to decay of any kind, than those of other ships. The staves of old tallow casks make a more durable fence than any kind of wood which has not been impregnated with oil. Sulphate of iron has also been used, as in Payne's process, (patented 1842,) a brief description of which will explain, in a general way, the operations practised for this kind of work. Several pieces of timber are arranged side by side on a sledge, bound together by hoops and chains, and thus introduced upon a railway into a long cylindrical iron vessel, the cover or end of which is then screwed on air-tight. Steam is now admitted, first to drive out the air, through a valve opened for the purpose, and then to form a vacuum, which partially occurs when a little of the cold solution of *sulphate of iron* is pumped into the vessel, by means of the steam-engine, to condense the steam; the vacuum is then completed by an air-pump, the liquid flows in as the air is exhausted, and is ultimately subjected to pressure by force-pumps also worked by the steam-engine; this fills the pores of the wood with sulphate of iron. After a few minutes the sulphate is allowed to flow out of the tank by the re-admission of air, the vessel is again heated with steam, and is similarly filled with *muriate of lime.* A double decomposition occurs *within the pores of the wood,* as the muriatic acid goes over to the iron, forming muriate of iron, and the sulphuric acid proceeds to the lime, forming sulphate of lime or gypsum; the latter remains principally in the pores, whilst the muriate of iron pervades the wood generally. The entire process of preparing the timber, including the filling and emptying of the tank, requires from one to three hours, according to the size of the cylinder. The wood becomes much heavier, indisposed to decay, less combustible, darker in colour, and also proof against rot and the ravages of insects. By certain variations of the process, and the employment of some other salts, the light-coloured English woods may be stained in a variegated manner throughout their substance, so as to be used for ornamental furniture, but the principal application hitherto made of the process is for preparing timber for railway purposes, and for building, especially the wood used in piles and wet foundations.

In addition to timber-trees, a vast variety of woods are used for ornamental purposes. In a series of papers contributed by Professor Forbes to the *Art Journal*, on "Woods used for Ornament and Purposes of Art," some clear distinctions, definitions, and descriptions are given, which are here, with the permission of the publisher, abridged for the profit of the reader.

The term *wood* is commonly applied to those portions of the vegetable axis that are sufficiently hard to offer considerable resistance and solidity, so as to be used for purposes requiring various degrees of firmness and strength. Every flowering plant is composed of an axis, and the appendages of the axis; the former consisting of the stem and root, the latter of the leaves and flowers. In trees, shrubs, and under-shrubs, the axis is said to be *woody;* in herbs it is termed *herbaceous.* In the former the stems are permanent, and do not die to the ground annually, as is the habit of the latter. A shrub, a tree, an under-shrub, a bush, are merely gradations of magnitude in perennial plants; woods valuable for purposes of Art and Manufacture are derived from all of them. But as bulk and dimensions are necessary to make timber available for extensive use, by far the greater part of our ornamental woods are derived from trees. There are, however, some remarkable exceptions. The wood of roots is different in structure from the wood of stems, and the same tree may furnish two very different kinds of ornamental wood, according as they are derived from its ascending or its descending axis. The wood of the inner portions of a stem may be of very different colour and quality from that of its outer parts. In the immediate neighbourhood of the origin of branches, it may exhibit varieties of pattern, such as to render it greatly more ornamental than elsewhere, and in some cases, when under the influence of morbid growth, reveals additional beauties, so as to be prized for qualities which in nature are defects. If we take a number of transverse sections of wood, and compare them one with another, it will soon become evident that there are two principal types or modifications of structure. Compare a cross cutting of oak or plane with a like portion of "Palmyra" wood, and you will see the differences between them strongly contrasted. In the former, the layers of wood are ranged in concentric circles round the central pith, and are encased externally in a bind-

ing of bark, itself composed of distinct and differently organized portions. In the latter, there is an uniform appearance throughout the section, the substance not being disposed in concentric rings, but appearing as if a bed or ground of one kind was studded with specks of another order of tissue. These are not slight dissimilarities: they indicate differences of the greatest structural importance in the economy of the respective trees. Corresponding with them are peculiar modifications of every portion of the plant's organization. The external aspect of the plants of either type is altogether unlike that of the other. The part played by the tree in the landscape; the share it has in determining the peculiarities of scenery; the sentiment, so to speak, that it gives to the living picture—are mainly the results of the modifications of external form, originating in minute structure. Were it not that among woods used for ornamental purposes, the first-named type has by far the most numerous representatives, these differences would affect still more than they now do, the operations of the cabinet-maker. If we place a thin slice of a young oak or plane under the microscope, we see how complicated is its anatomical structure. In its central portion is the pith, composed of minute and mostly hexagonal cells,—little membranous bladders, that in the early stages of the tree's growth play a more important part than they do during its maturity. A great development of pith, as in the Elder, renders the wood comparatively valueless. Around this central tissue is a circle, chiefly composed of very long spindle-shaped cells, each enclosing a loose spirally-coiled thread. This is the *medullary sheath* of botanists. It is interrupted at intervals by radiating extensions of the pith that proceed across the next element of the stem, the true wood, towards the circumference. The wood encircles in successive layers the pith and its sheath. It is composed of tough fibres, mingled in more or less orderly arrangement with vessels of various kinds, some of which give it porosity. In the first year of the stem's growth, there is but a single layer of the wood. Year after year a fresh circle is superadded, and, in temperate climates, at least, we can pronounce with certainty on the age of a tree by counting the number of annual rings of growth displayed in its transverse section. In this manner, the age of certain trees has been inquired into; and many, especially planes, cedars, limes, and oaks, have been shown to have lived the patriarchal existence of nearly, or quite, a thousand years; while yew-trees grown in our own country, have exhibited unmistakeable signs of thrice that vast longevity. Around the wood are successive layers of bark, the innermost fibrous, and investing the newest layers of wood; the middle and outer ones cellular, and often forming corky developments. Out of the inner layers of bark of certain trees, cordage and matting are sometimes constructed; the lime especially furnishes such materials. The beautiful lace-bark is this inner layer in the *Lagetta lintearia*, one of the spurge-laurel tribe. The surface of the bark is itself invested with a thin pellicle of epidermis, constituting the skin of the tree. This division into pith, wood, and bark, is characteristic of the stems of exogenous or dicotyledonous trees. In the stems of endogenous or monocotyledonous trees—the Palmyra wood of commerce, or the section of a rattan are examples—there is no such distinction into these three portions. The central mass is, it is true, more or less cellular and pith-like in not a few of the Palm tribe, but it is so because fewer bundles of vessels and fibres stud it than are to be found near the circumference. It is not separated from the central portion by a sheath of spiral vessels, nor do medullary rays proceed from it. The stem, besides, is not invested by peculiar and distinct bark, though the densely-packed and tough fibres of its exterior often form an extremely tough case. If we cut down the stem of an oak or plane, lengthways, and compare it with a similar section of a palm, we see that the differences so conspicuous in the transverse, are equally manifest in the longitudinal section. In the former, the several parts are ranged in lines, the sections of circles, parallel to the central pith; but in the latter, the lines of tissue describe more or less evident curves manifested by the direction of the darker streaks, indicating the presence of fibrous and vascular bundles. These curves, if traced through the entire length of the stem, would be found to proceed from the base of the leaves at its summit, to run inwards towards its centre, and then outwards towards the exterior, changing their minute structure in the several portions of their course, and becoming at last exceedingly tough and fibrous, so as to constitute the hard external investment. There are peculiarities of anatomical structure distinctive of some exogenous trees, and which materially affect the quality and properties of the wood. If we compare the section of a tree of the pine tribe with that of an oak or elm, we shall find in the former an absence of the conspicuous pores in the annual belts of wood that are so plainly seen in the latter; and with the aid of the microscope, we shall see that this difference is due to minute peculiarities of organization. In the pine, the peculiar vessels called *dotted ducts*, that give porosity to wood, are wanting; whilst the woody layers are made up of disk-marked or punctated fibres that are not to be seen in the oak or elm, or in other trees than those that have cones for their fruit, and their immediate allies. So marked and constant is this feature of their structure, that sections taken from fossil coniferous trees exhibit the curious disks that decorate their fibres; thus, by the aid of the microscope, we are enabled with certainty to pronounce upon the affinities of plants that grew countless ages ago, when every living creature on the earth's surface was specifically distinct from any one now existing.

The appearance styled *silver-grain* in wood is dependent on the cellular tissue of the medullary rays, and is, therefore, exhibited by exogenous woods only. It gives the streaks of glancing satiny lustre, that are so ornamental in many kinds of woods. In the oak and beech this appearance is

conspicuous. The inner layers of wood, after the tree has become aged, often become compact, and frequently different in colour from the new wood. They are then styled the *heart-wood.* Botanists term them the *duramen*, and apply the name *alburnum* to the outer layers or sap-wood. In the former, the tissues have become dry and dense, and charged with solidifying deposits, so as to prevent them aiding in the ascent of the sap. Often, too, they become more or less deeply coloured, so as conspicuously to contrast with the pale sap-wood. This difference is especially conspicuous in the ebony-tree, the black portion of which is the *duramen*, or heart-wood. In the oak, the heart-wood is of a dark brown hue. In all trees whose older woody layers undergo such changes, the heart-wood is highly prized for purposes of furniture. In willows, poplars, and chestnuts there is no difference of colour between the heart and sap-woods. Such are styled *white-woods.* As a general rule, the latter are not nearly so durable as the former. The wood of coniferous trees appears to be least perishable; a quality which is probably due to the peculiarities above noticed, of their anatomical structure.

The forests of the colder and temperate provinces of the Old World, as well as those of corresponding regions in America, are everywhere very similar in physiognomy, being composed either of coniferous trees, of which the *pine*, the *larch*, and the *fir* are characteristic examples; or of dicotyledonous trees, among which the *amentaceous*, or catkin-bearing kinds, are especially conspicuous. The timber they furnish is of great value for useful purposes, and, among the numerous varieties in which they abound, are several yielding highly ornamental woods. They want, however, the rich brilliant, and intense colouring of tropical woods, and are, for the most part, modest in hue.

Among the foremost in the list of European ornamental woods stands the *yew.* This venerable and picturesque tree is a native of most parts of Europe. It is the *Taxus baccata* of botanists, and is represented in North America by the very similar *Taxus canadensis;* by some they have been regarded as forms of the same species. The wood is close and fine in the grain—hard and compact; it is exceedingly durable, indeed incorruptible, and capable of taking a high polish. The colour of the heart-wood is rich orange-red, deepening into dark brown, contrasting with the rather scanty white sap-wood: elegantly veined and marbled portions may be taken from the branching regions of the trunk and roots. The sap-wood may be stained so as to resemble ebony. Furniture of exquisite beauty has been constructed of yew-wood; indeed it is admirably adapted for fancy cabinet-work, either in mass, or inlaid as veneers: the supply is said, however, to be insufficient. The wood of yew was once extensively used in the making of bows.

The *cedar* is a native of the warmer temperate mountainous regions of Asia. The celebrity of the cedar of Lebanon dates from a very high antiquity; and the reputed value of its timber for ornamental and cabinet purposes, has been placed on record from very ancient times. Either, however, more coniferous trees than one have been included under the popular appellation—or the qualities of the wood have sadly degenerated, for that of the existing cedar of Lebanon is by no means remarkable for beauty, durability, or sweetness of odour, all of which properties were pre-eminently ascribed to it. The tree itself is as grand as ever; one of the most majestic of arborescent elements in the landscape. It was extensively used among the ancients. Nevertheless, this wood, such as we now know it, is not one to choose for carving or house-construction. It is very light and spongy, of a reddish-white colour, scented like ordinary pine, and not at all durable. It is possible that other kinds of coniferous trees were confounded by the ancients with the tree cedar. The Himalayan deodar, a tree very closely related to the cedar of Lebanon, really possesses all the good qualities for which the latter has been so long celebrated. Travellers in the East, in writing about cedars, often confound various kinds of arborescent juniper under that name. The cedar-wood, sometimes used for the making of drawers in cabinets, and familiar in the shape of pencils, is the product of an American species of juniper, the best quality being that furnished by the Bermudan juniper-tree; a less valued sort is yielded by the *Juniperus virgineana*, a native of the Atlantic United States, south of Lake Champlain. It is a ragged tree, some thirty feet or so high, growing on dry rocky hills. In both these pencil-cedars, it is the heart-wood which possesses the desired colour and qualities. Our native Juniper, though but a shrub, produces a wood of worthy quality could it be obtained of sufficient dimension and quantity. Its colour is yellowish brown, often beautifully veined; it gives out an aromatic odour. It is sometimes used for turning; cups are occasionally made from it, and walking-sticks. The wood of the Cypress was much used by the ancients for ornamental furniture, especially in Greece, where that beautiful tree is indigenous. It is among the most durable of all woods.

The numerous race of pines and firs for the most part are more useful than ornamental, so far as their timber is concerned. Some of them, however, afford wood with many desirable qualities for furniture-making. The stately spruce, that constitutes so fine an element in the scenery of Northern Europe, and rears its tapering trunk to the height of 150 feet and more, supplies a light and fine-grained wood, easy to work in every direction, and capable equally of taking a high polish, or a black stain. It is a good wood to bear gilding, and, from the facility with which it may be glued, is much used for lining furniture, and in the construction of musical instruments. Though presenting no depth of colour, when polished and varnished it is highly ornamental, and in Norway and Sweden pretty and effective household furniture of all sorts is made of it. The wood of the larch, a native of the mountain ranges of Central Europe, is similarly used with like effect. It is of a yellowish or reddish hue, very strong, durable, and close-grained.

It takes a high polish, and has the great advantage over spruce wood in being free from knots. Ever since the days of the ancient Romans, it has been used in the Arts, for the making of panels and palettes. Another Alpine tree, the *Pinus cembra*, a native of the highest regions of pines, and among the most soaring of its tribe, living at heights of 5 and 6,000 feet above the sea, furnishes a very durable, fine-grained, and easily-worked wood, remarkable for fragrance, which it retains for centuries, much to the annoyance of bugs and moths, pestilent creatures that have an unconquerable antipathy to its neighbourhood. The colour of its heart-wood, which is valuable for wainscoting, is a pleasant light brown. The facility with which it can be carved has led to its use among the shepherds of Switzerland and the Tyrol, who cut it into ornaments; the little figures, houses, &c., so often brought as curiosities from those countries, are very frequently cut out of the wood of *Pinus cembra*. In the United States of America, the wood of the Weymouth or white pine, *Pinus strobus* of botanists, a tree of majestic dimensions, which has been known to tower even to the height of 250 feet and more, is used for furniture-making. The specific gravity of its wood is said to be less than that of any other, except Lombardy poplar. In consequence of its altitude, bulk, and straightness, it yields timber of greater size than is furnished by any other soft-wooded tree. When varnished, its wood displays a pleasing yellowish or light red hue. It is a beautiful material for wainscoting, and well adapted for wood-carving. Hence it is used for the making of picture frames, and is the favourite American material for the figure-heads of ships. For the latter purpose, the *Pinus Laricio*, or Corsican larch, the heart-wood of which is locally much used by cabinet-makers and wood-carvers, is employed in the Mediterranean, as well as that of the silver fir, *Pinus picea*, one of the noblest trees of its family, a native of Central Europe and Western Asia. The larch of America is a different tree from that of Europe; it yields a close-grained and compact reddish or grey wood, remarkable for strength and durability.

The wood of ancient coniferæ, preserved in the peat bogs of Ireland, the Isle of Man, and elsewhere, and thus deeply stained with rich colouring matter, has sometimes, though not so often as that of the bog oak, been applied to ornamental purposes with considerable effect. The bog yew of Ireland has especially been so employed, and some beautiful examples of it were displayed at the Great Exhibition, where were also specimens of veneers taken from the roots of the bog Scotch fir, well worthy of notice, and suggestive of a more extensive use of this pre-Adamite timber for cabinet-making.

The *oak*, the *chestnut*, the *beech*, the *plane*, and the *poplar*, all represent genera belonging to the order *Amentaceæ*. The members of this group are all either trees or shrubs, and not a few yield timber of value. Preeminent stands the oak, a name applied to most species of the genus *Quercus*. They furnish harder, tougher, more compact, and more durable woods than most trees. The oak of Britain is the *Quercus robur*, of which there are two very marked forms, that have been regarded as distinct species and designated by different names. It was at one time supposed that the wood of one of these varieties was much superior to that of the other, but we may regard this belief as unfounded in fact, since each kind has advocates for its superiority. The beauty of the wood of oak when used for furniture and wainscoting depends partly upon its pleasing, unassuming yellow-brown hue, so inoffensive, and at the same time so attractive, to the eye, and partly upon the variety and brilliancy of the silvery streaks, lines, and curls that break what would otherwise be the monotony of its colour. These are caused by various arrangements and sections of the rings of annual growth, and of the medullary rays or wedges of cellular tissue. Of course the beauty and variety of the surface will depend much upon the mode of treatment of the plank by the cabinet-maker, who has to take into account all the peculiarities of the grain if he would develop the qualities of his material. Mr. Holtzapffel remarks, that if we inspect "the ends of the most showy pieces of wainscot oak and similar woods, it will be found that the surface of the board is only at a *small* angle with the lines of the medullary rays, so that *many* of the latter crop out upon the surface of the work; the medullary plates being seldom flat, their edges assume all kinds of curvatures and elongations from their oblique intersections." The value of timber, even of the same species of oak, considered as ornamental woods, differs according to the locality in which it has been grown, and the best wood for ship-building and ordinary purposes is not always that most suitable for furniture work. Many of the finest examples of mediæval carving were executed in the almost imperishable wood of *Quercus robur*. The Turkey oak, *Quercus cerris*, furnishes a wood said by some to be highly ornamental; but this good character is somewhat doubtful. The heart-wood of *Quercus ilex* is also reputed to have merit, nor should the cork-tree, another species of oak, be passed without remark.

The Beech furnishes a wood which varies in properties and value, according to the soil and locality upon which it is grown. When grown in poor and mountainous ground, the wood is white; but if the produce of rich soils and plains, it is more or less red. It is hard, unequally grained, yet close in texture, and liable to the attacks of insects; nevertheless it is much used for furniture-making, framework, joinery, and turning. Though not capable of taking a very high polish, it stains well, so as to simulate high-coloured foreign woods, such as rose-wood and ebony. It is well adapted for the purposes of the wood-cutter, and for carving into ornaments of frames, and moulds for culinary purposes. In the Northern United States, the wood of the American beech is extensively used for the making of chair-posts, and is turned into large bowls, trenchers, and trays.

A tree much used for the manufacture of furniture in North America, is the *chestnut*, apparently a different species from that which is indigenous in the

Old World. It is said to be among the best of woods for constituting the framework of articles to be covered with veneers of more valuable materials, and to be extensively used in the manufacture of bureaus and sofas. The wood of the *European chestnut* (*Spanish chestnut*), has at times been much used for carving and cabinet-work, and resembles that of oak, but is deficient in "flash," and is not held in high esteem. In the Levant, and eastwards, furniture is made from the *oriental plane*, not deficient in beauty, especially when constructed from the brown and very old wood, and sometimes beautifully damasked. The tree itself is one of the grandest features in the Turkish landscape, and attains gigantic dimensions. The occidental plane is said to yield a close-grained, light-coloured wood, capable of high polish, but liable to warp. It is used in the making of musical instruments. *Birch-wood*, from the *Betula alba*, is used in Europe for the making of toys. The fine wood called *Russian maple* appears to be a birch. The *black birch* or *mountain mahogany*, *Betula lenta* of North America, a tree which ranges from Nova Scotia southwards to Georgia, yields a strong, firm, durable, easily-worked wood, well adapted for panelling and furniture; its colour is a delicate rose, deepening, but not becoming sombre, with age. The *paper birch*, *Betula papyracea*, whose bark is so useful to the Canadians, who make of it their simple, but effective and elegant canoes, also baskets, boxes, and folios of singular lightness and beauty, many of which were conspicuous in the Canadian department at the Great Exhibition, is valuable for its timber also. The heart-wood is red; the sap-wood is white, with a pearly lustre, and capable of taking a high polish. Furniture is made from it in Canada and the States, and elegant cabinet-wood from the feathered and variegated portions taken from the regions of the trunk whence the branches spring. The orange and deep reddish wood of the *alder*, when knotted and curled, is used occasionally for ornamental work, and frequently for toy making, as are also the *poplars*, yielding white and clean-cutting wood, easily worked and carved, and capable of being used as a substitute for lime-tree. Nor must we omit all mention of the *willow* and the *osier*, the softest and lightest of our European woods, valuable for bonnet-making, baskets, &c., when planed into chips.

Among the natural orders that have affinities with the catkin-bearing trees, are the *Walnut* and the *Nettle* tribes. In the former, we find the valuable tree which gives the group its name. The repute of walnut timber for beauty and capability is of ancient date, since we find it praised by Greek authors for furniture; and though for a time exotic woods supplanted it, there is as much preference shown for it now as ever. In value it will probably increase, since fine trees are not over-common; and the application of the wood to the making of gun-stocks during the war, led to a prodigious destruction of European walnut-trees. The combined qualities of lightness, rich-colouring, solidity, compactness, durability, facility of working, and freedom from warping, place the heart-wood of the walnut high in the scale of furniture timber. Many very beautiful efforts of the artist-carver have been executed in this material. The veined and cambleted roots yield beautiful veneers, highly esteemed for ornamental work. The yellowish sap-wood can also be used for permanent purposes, when rendered preservable and defended against the attacks of insects, by the simple process of boiling in walnut oil. The *true walnut*, or *Juglans regia*, is believed to be a native of Persia. The *black walnut*, *Juglans nigra*, is a North American tree, of considerable dimensions, growing to a height of 60 or 70 feet, and attaining a diameter of 3 or 4 feet. Its wood is much used for furniture in America, and numerous fine examples of it were displayed in the Crystal Palace. It is imported into England for cabinet-making. Its colour is dark violet or purplish grey, or purple deepening with age. The grain is fine; tenacity, hardness, strength, durability, and capacity for polish are among its good qualities. The *butternut*, *Juglans cinerea*, is another American species of this genus, a low tree, yielding a pale red, durable, light wood, with considerable capabilities for ornamental uses. The *hickory* also belongs to this tribe, though to a different genus, *Carya*. Its timber is more useful than ornamental. The *elm* is a member of the Nettle tribe. The excrescences of its trunk are employed for decorative purposes. The *mulberry* is occasionally used for fancy purposes, and the *Maclura aurantiaca*, an allied tree from Arkansas, is said to yield a close-grained, durable, hard, and polishable wood, remarkable for its rich saffron-yellow colour, well worthy of the attention of cabinet-makers.

Among the Mediterranean trees, not natives of middle Europe, is the *Celtis australis*, or *Nettle* tree. It furnishes the *bois de Perpignan*, an extremely compact wood, hard and dense, and capable of taking a high polish. Cut across the grain and polished, it resembles satin-wood. In the south of Europe, it is used for furniture, flute-making, and carving into figures of saints, and circulates extensively over many countries in the shape of handles for whips. The American *nettle-tree*, called also *beaver-wood* and *hoop-ash*, is a different species, and rare, but has probably similar qualities. The *hack-berry*, another American kind of *Celtis*, is one of the finest of the forest trees on the banks of the Ohio; and yields, according to Michaux, a fine-grained and compact wood, perfectly white when first cut, and apparently possessed of valuable ornamental qualities. The *Zelkova*, a North Persian species of *Planera*, a genus of the Nettle family, yields a fine furniture wood, not much known.

The *box* belongs to the *spurge tribe*. It produces a warm yellow wood, much used by the turner, and well adapted for the construction of flutes and similar musical instruments. It is the yellow wood which we often use in the shape of rules and scales, and it is also the chief wood employed in wood-engraving. It is sometimes beautifully mottled. In Britain we have the box growing wild and luxuriant in Surrey, as at Box-hill; but the chief supply of this wood is derived from the southern parts of Europe, and from

Asia Minor. A distinction is drawn between "Turkey" and "European" boxwood. The latter is more curly, softer, and paler than the former. Dr. Royle has called attention to a different species of *Buxus*, a native of the Himalayas, yielding a wood possessing similar qualities with that in common use, and having the advantage of being found of considerable size and thickness. The *ash* and the *olive* are members of the olive family. The former familiar tree yields a timber remarkable for toughness and elasticity, and excellent for machine and agricultural purposes, but not much used for finer applications. When, however, the grain is zigzag, it is adapted to the making of furniture of considerable beauty. Olive-wood is imported from the Mediterranean countries. It is veined with dark grey, and resembles boxwood in texture, but is softer. The knotted and curled roots are made into embossed boxes. This is done by means of pressure in engraved moulds of metal. The *holly* type of the family *Ilicineæ*, whilst among the most ornamental of our smaller native trees, is at the same time much valued for its wood, which is very fine grained, and, when properly prepared, being satiny, close in texture, and not liable to stain superficially, though capable of taking an intense dye. It is highly prized by the manufacturer of Tunbridge-ware, and much used in the making of screens, squares of draft boards, and lines of cabinet-work. The holly of North America has similar qualities, and is applied to like uses.

In the family of *heaths*, there is one European genus, whose members furnish a wood adapted for the cabinet-maker, although not much used. This is the *Arbutus* or *strawberry-tree*, of which there is more than one species indigenous and abundant in the countries bordering upon the Mediterranean. A colony of the *Arbutus unedo* flourishes upon the islands and shores of the Lakes of Killarney. The hard and close-grained, warm-tinted wood of this tree is occasionally used by turners, and converted into ornamental articles, such as inkstands and bookcases. Among the many-petalled flowered exogens are not a few tribes that include trees of value for their timber as well as for the excellence of their fruit or the elegance of their flowers. The first we have to mention, however, is not very remarkable in any of these respects; it is the *cornel* or *dogwood*, *Cornus sanguinea*, a shrub abundant in our English thickets. Its wood is used for skewers and such ignoble instruments; its higher use is that to which it is applied by the watchmaker and optician, who avail themselves of its freedom from grit, to make instruments of its splinters for cleaning fine machinery or lenses. An American species, the *Cornus florida*, produces a hard, heavy wood, capable of taking a good polish, and used on the other side of the Atlantic as a substitute for box-wood. The *Araliaceæ*, a natural order to which the ivy belongs, may be mentioned here incidentally on account of the substance so well known as *rice-paper*. This was long supposed to be the pith of a leguminous plant; its true nature was not made known until lately, when Sir William Hooker demonstrated that it was the pith of an araliaceous tree. A living plant had been procured with great difficulty from the Chinese, and was sent to England, but died on the passage. It is said to be exclusively a native of the island of Formosa.

In the family of *Rosaceæ* we find the greater number of our useful woods derived from trees with conspicuous flowers—not from roses and brambles, but from the members of the apple and plum tribes, which are sections of this beautiful group. The wood of the *apple* itself is one of the most used. It is moderately hard, often rich in hue and close-grained. It works well and clean, and is adapted for turning. Like the other woods of the tribe, it is employed for chair-making. The bole of the tree only is used, and the wild apple or crab is often preferable to the cultivated; as also with the pear, the light brown wood of which is valued by the maker of Tunbridge-ware. It carves well, cutting cleanly in all directions of grain. It requires to be well seasoned, however. It takes a black dye with facility. Blocks for calico-printing and paper-staining are often cut out of it. The *service-tree* is said to yield a useful dark red wood, tough and lasting. The *medlar* is seldom used, its wood is pale and rather soft. The *mountain ash* produces a hard and fine-grained, light-coloured wood, capable of taking a good polish: a character applicable also to that of the common hawthorn. Among the best rosaceous furniture woods is the *Cherry*. It is of a pale reddish hue darkening to brown: its grain is hard and close. It works easily and takes a fine polish, becoming of a ruby tint when oiled or varnished, and takes a good stain. It is extensively used by cabinet-makers. Nor should cherry pipe-sticks be forgotten. The *black cherry* of the United States, (*Cerasus serotina*,) a tree that grows even to 100 feet in height, yields a fine, close-grained, light red wood, darkening with age, and beautifully glanced, with abundant silver-grain. The attention to our cabinet-makers might be directed with advantage to this tree. The wood of the *Plum* is richer in hue than that of the cherry, but is not so serviceable. It, as well as that of the *Blackthorn*, is used in the making of Tunbridge-ware and other fancy cabinet-work. That of the *Apricot* has a fine and hard grain. The *almond-tree*, especially when wild, is said to furnish a valuable wood, but which is little known or used. The great order of leguminous plants, the Pulse tribe, is rich in trees, but not much so in temperate climates, nor is there any ordinary tree of the group upon which stress can be laid. That best known is the *locust-tree*, or what is commonly, though incorrectly, called by the name of *Acacia*. It is the *Robinia pseudacacia* of botanists. It produces a yellowish or reddish wood, compact and lasting, with a fine texture and abundant silver-grain. It is used for turners' work, for furniture and for cricket-stumps. The dark brown or greenish wood of the *Laburnum*, streaked with white silver-grain, is well adapted to ornamental purposes. Some other arborescent species of *Cytisus* differ from it in tint and quality. The fustic of the Levant, a yellow dyewood, belongs to the order *Anacardiaceæ*, so named after the *cachew-nut* genus. In that of *Celastraceæ* is

included the well-known *Spindle-tree*, furnishing a yellow wood fit for such articles as thread-reels and bobbins. Its charcoal has peculiar merits for the purposes of the artist.

The wood of the European *lime-tree* has qualities which render it highly valuable for ornamental carving, although it is of little use as building timber. The beauty of its creamy white colour, the closeness and firmness of its grain, its softness and lightness, render it admirably adapted for the purposes to which it is chiefly applied. Carriage-panels, sounding-boards for pianos, toys, and boxes are made of it, as well as furniture intended to be inlaid. It is one of the materials used in wood-mosaic; and the white portions of the patterns executed in Tunbridge-ware are mostly constructed of lime-tree. Its fame for purposes of sculpture in wood dates from very ancient times, and it is therefore mentioned with praise by more than one classic poet. Some of the finest of the carvings of Grinling Gibbons were executed in lime. Although this tree is extensively grown in Britain, it is not planted now so frequently as formerly, and although believed by many botanists to be a native of our country, it must practically be regarded as a foreign wood. The north and east of Europe are its chief indigenous haunts, and in Lithuania there are extensive forests of it; the chosen places for rearing of bees, whose honey, if they be fed upon the flowers of the lime-tree, becomes peculiarly delicious in flavour. In North America its place is taken by a representative species, growing under similar conditions, and furnishing a wood possessing similar qualities, soft, white and close-grained; it is much used by the cabinet-makers of the States, and by the sculptors of figure-heads for vessels on the Transatlantic rivers.

In the *maple tribe* are several valuable trees for ornamental purposes. The *sycamore* is one of the most familiar. It is compact and fine-grained, rather soft, easy to work, susceptible of polish, and not liable to warp. When young, it is white and silky; when old, yellowish or brown. It is sometimes variegated, and is then most sought after. In days of yore it furnished the wooden platters and other household instruments that reposed upon the old English dresser. Now it is extensively employed in the manufacture of musical instruments and purposes of turnery. The *common maple* was more honoured anciently than now, and by the Romans was chosen for the making of ornamental tables. It is fine-grained, and capable of taking a high polish. Butter-prints and such like articles are carved out of it. It is well adapted for turnery. Its knotted root-wood is highly ornamental, and applied to the manufacture of fancy snuff-boxes, &c. More valuable are some of the maples indigenous to North America. What is called the *bird's-eye maple*, remarkable for the beauty of the figures described in the section of it, is not a peculiar kind, but particular portions of the tree, full of small knots or embryo-buds; these, according to the direction in which they are cut, describe various patterns. What is called *curled maple* is dependent for its peculiarities on the direction of the woody fibres, and is also no special sort. Both curled and bird's-eye varieties are usually procured from the *Acer saccharinum* or *sugar-maple*. It is a tree that in the forest grows to 60 or 70 feet high before branching, indigenous to Canada and the Northern States. Its wood is compact, hard, and capable of taking a fine polish. It is much valued by cabinet-makers. The *red maple* of North America is another tree esteemed for purposes of furniture. Its wood is reddish-white, fine-grained, and close, with narrow strips of silver-grain. It polishes well, and is sometimes curled and blistered; the former qualities, as in the sugar-maple, depending on an undulation of the grain; the latter, upon the same cause that produces the bird's-eye appearance. It is extensively used for the making of common furniture in the States, but is deficient in strength and not very durable. The *white maple*, (*Acer eriocarpum*,) another American species, is used for the making of tools. The *Acer platanoides* of the mountainous regions of Europe is applied to similar purposes with the sycamore. The beautiful wood known as *Russian maple* is said to be really the product of a species of birch. The *black ash* of North America, (*Negundo fraxinifolium*,) yields a yellow wood adapted for inlaying.

In the order *Sapindaceæ*, we find one tree of temperate climates furnishing an ornamental wood. It is the *horse-chestnut* (*Æsculus hippocastanum*), no relation, however, to the true chestnut. It yields a soft, close-grained, white wood, turning well, and much used in Tunbridge-work. The white backs of brushes are often made of it. It is employed in inlaying. The yellow wood of *orange-trees* is occasionally employed for ornamental purposes, but is of little value. The *tulip-tree* (*Liriodendron tulipifera*), well known now in our gardens, is a native of the Western United States, where it grows to a height of 140 feet. It is one of the Magnolia tribe, and is often set down as producing the well-known and beautiful tulip-wood. This is a mistake; its wood is white, soft, and fine-grained. It is not much valued.[1]

The above notice includes some of the most important woods employed in the useful and ornamental arts. A few woods of especial interest have been noticed under separate heads. [See MAHOGANY.] The table on page 1022, compiled by the late Mr. Holtzapffel, gives the names of most of the woods employed in Great Britain, together with the uses to which they are applied.

The quantity of wood annually imported into Great Britain is about 2,000,000 loads, or 100,000,000 cubic feet; hence it is of great importance to ascertain from what quarters this immense amount can be obtained with the least risk of failure in the supply. The collections of woods brought together at the Great Exhibition, amounting to several thousand specimens, were in this respect most valuable, and revealed a large number of woods which had been previously wholly unknown to commerce, and some of which were even unknown to the botanist. There are now

(1) The "Art Journal," 1853.

TABULAR STATEMENT OF THE WOODS COMMONLY USED IN GREAT BRITAIN.

FOR BUILDING.

Ship-building.

Cedars.
Deals.
Elms.
Firs.
Larches.
Locust.
Oaks.
Teak, &c. &c.

Wet works, as piles, foundations, &c.

Alder.
Beech.
Elm.
Oak.
Plane-tree.
White cedar.

House-carpentry.

Deals.
Oak.
Pines.
Sweet chestnut.

FOR MACHINERY AND MILL-WORK.

Frames, &c.

Ash.
Beech.
Birch.
Deals.
Elm.
Mahogany.
Oak.
Pines.

Rollers, &c.

Box.
Lignum vitæ.
Mahogany.

Teeth of wheels, &c.

Crab-tree.
Hornbeam.
Locust.

Foundry patterns.

Alder.
Deal.
Mahogany.
Pine.

FOR TURNERY.

Common woods for toys: softest.

Alder.
Aps.
Beech } small.
Birch } small.
Sallow.
Willow.

Best woods for Tunbridge-ware.

Holly.
Horse-chestnut } white woods.
Sycamore } white woods.
Apple-tree } brown woods.
Pear-tree } brown woods.
Plum-tree } brown woods.

Hardest English woods.

Beech, large.
Box.
Elm.
Oak.
Walnut.

FOR FURNITURE.

Common furniture, and inside works.

Beech.
Birch.
Cedars.
Cherry-tree.
Deal.
Pines.

Best furniture.

Amboyna.
Black ebony.
Cherry-tree.
Coromandel.
Mahogany.
Maple.
Oak, various kinds.
Rose-wood.
Satin-wood.
Sandal-wood.
Sweet chestnut.
Sweet cedar.
Tulip-wood.
Walnut.
Zebra-wood.

FOREIGN HARD WOODS, SEVERAL OF WHICH ARE ONLY USED FOR ORNAMENTAL TURNERY.

1. Amboyna.
2. Beefwood.
3. Black Bot. B. wood.
4. Black ebony.
5. Box-wood.
6. Brazil-wood.
7. Brazilletto.
8. Bullet-wood.
9. Cam-wood.
10. Cocoa-wood.
11. Coromandel.
12. Green ebony.
13. Green heart.
14. Grenadillo.
15. Iron-wood.
16. King-wood.
17. Lignum vitæ.
18. Locust.
19. Mahogany.
20. Maple.
21. Mustaiba.
22. Olive-tree and root.
23. Palmyra.
24. Partridge-wood.
25. Peruvian.
26. Princes-wood.
27. Purple-wood.
28. Red sanders.
29. Rosetta.
30. Rose-wood.
31. Sandal-wood.
32. Satin-wood.
33. Snake-wood.
34. Tulip-wood.
35. Yacca-wood.
36. Zebra-wood.

Nos. 3, 8, 16, 33, and 34, are frequently scarce.

Nos. 3, 5, 8, 9, 10, are generally close, hard, even-tinted, and the more proper for eccentric turning, but others may also be employed.

Nos. 4, 5, 10, 12, 14, 17, 18, 19, 30, 32, are generally abundant and extensively used. All the woods may be used for plain turning.

MISCELLANEOUS PROPERTIES.

Elasticity.

Ash.
Hazel.
Hickory.
Lance-wood.
Sweet chestnut, small.
Snake-wood.
Yew.

Inelasticity and toughness.

Beech.
Elm.
Lignum vitæ.
Oak.
Walnut.

Even grain, proper for Carving.

Lime-tree.
Pear-tree.
Pine.

Durability in dry works.

Cedar.
Oak.
Poplar.
Sweet chestnut.
Yellow deal.

Colouring matter.

RED DYES.

Brazil.
Brazilletto.
Cam-wood.
Log-wood.
Nicaragua.
Red sanders.
Sapan-wood.

GREEN DYE.

Green ebony.

YELLOW DYES.

Fustic.
Zante.

SCENT.

Camphor-wood.
Cedar.
Rose-wood.
Sandal-wood.
Satin-wood.
Sassafras.

The woods used in our Government yards for ship-building are as follows:—

OAKS.—English. Adriatic. Italian. Sussex. New Forest. Canada, white and red. Pollard. Istrian. Live-oak. African, and also Teak.

PINES.—Yellow. Red. Virginian. Nil red. Pitch pine. Riga.

FIRS.—Norway and American spruce fir. Dantzic and Adriatic fir.

LARCHES.—Hackmetack. Polish. Scotch. Italian, 1, 2, 3. Athol. Cowdie, or New Zealand larch.

CEDARS.—Cuba. Lebanus. New South Wales, and Pencil cedar.

ELMS.—English and Wych elm.

MISCELLANEOUS WOODS used in small quantities.—Rock elm. English and American ash. Birch, black and white. Beech. Hornbeam. Hickory. Mahogany. Lime-tree. Poon-wood. Lignum Vitæ, &c.

eight descriptions of timber admitted as *first-rate* for ship-building purposes, and one of these has only been so ranked since the opening of the Great Exhibition. They are:—1, *English oak;* 2, *American live-oak;* 3, *African oak;* 4, *Morung saul;* 5, *East Indian teak;* 6, *Green-heart;* 7, *Morra;* 8, *Iron-bark* (the newly admitted wood). Of the above, the Morra, and the Green-heart, are trees of British Guiana. The timber called African oak is the produce of an unknown tree, certainly *not* an oak. The American live-oak is met with in the southern states of North America, but never in inland forests or at a distance of more than 15 or 20 miles from the sea, the air of which seems necessary to its existence. It is 40 or 50 feet high, and a close-veined, even wood. The Morung saul is an Indian tree, as well as the better known and valuable Teak. The Iron-bark is from New South Wales, and has a density of 1·426, and a strength of 1·557, (English oak being called 1·000.) It resembles plain brown Spanish mahogany, but it seems to be the heaviest and most solid of all woods. From the same quarter of the world were derived some specimens of a gigantic species of Eucalyptus. One of these trees, 14 feet in diameter, was cut down for the purpose of our Exhibition, and a plank of that width would have been sent over, if saws of the requisite length could have been procured. Two slices or sections, however, were cut from the stem of one of these magnificent trees: the larger section, taken at the height of 4 feet from the ground, was 6 feet in diameter, and the smaller section, at a height of 134 feet, just below the first branch, was nearly 3 feet in diameter. Several beautiful ornamental woods also came prominently into notice at the Great Exhibition, such as the *musk-wood, black-wood,* and *Huon pine,* of Van Diemen's land, and the *red ebony* of South Africa. The collection of East Indian woods by Dr. Wallich contained about 450 specimens, and consisted of the woods of Nepal, those of Tavoy, those of Gualpara, and those grown near Calcutta. Other collections by Dr. Boyle, Colonel Frith, and other gentlemen from various parts of India, including woods of the Indian Archipelago and Ceylon, formed upwards of 30 distinct collections, the particulars of which are given in the Jury Report, Class IV.; where it is remarked, that "the nature and properties of many of these Indian woods is very little known, and though, for the most part, it is not probable that it would be found worth while to import them into Europe, yet their importance to India is every year increasing, and must necessarily continue to do so, as the demand for timber in India for railways and other engineering purposes increases. For such uses it is desirable, not only that the wood should be strong and not liable to decay from mere exposure to the weather, but also, that it should work freely, and be able to withstand the ravages of the various insects to which wood of all kinds is more or less exposed in tropical countries. It is true, that even the most porous and spongy woods may be rendered capable to some extent of resisting all such influences, by being impregnated with various solutions, as in the processes of Kyanizing, &c., but it is obviously far better, when possible, to select such woods as are naturally saturated with resinous and aromatic substances, as in this latter case all cost of preparation is saved, besides that the preserving matter is far more perfectly disseminated throughout the whole of the wood than can possibly be effected by any artificial process after the tree is felled. In examining the comparative value of different sorts of wood, it is of the first importance to ascertain the nature of the encrusting matter deposited throughout the cells and tubes of the wood. For all practical purposes those woods appear to be best in which the cells are lined with resinous matter, those filled with hygroscopic gummy matter are, for the most part, of less value; they are seasoned with difficulty, and are always more liable to decay. The best woods are those having a strong fibre, protected from all external influences by a coat of resinous matter, or at least of a matter insoluble in water, and one which does not attract atmospheric moisture."

The table on page 1024 (abridged from the Jury Report) contains a list of the woods grown in Great Britain, specimens of which were exhibited, with certain interesting particulars attached.

The total annual importation of timber into Great Britain (the average quantity of which is stated, p. 1021) is entered under the several designations of timber, or unsawn wood, deals and planks, or sawn wood, teak-staves, and lath-wood.

The following table shows the countries from which wood was chiefly imported in the year 1849:—

	Timber.	Deals.	Teak.	Staves.	Lath-wood.
Russia	41,419	173,586	—	325	15,539
Sweden	28,679	79,843	—	150	1,119
Norway	28,930	50,805	—	95	103
Prussia	117,470	35,006	—	19,213	6,169
Hanse Towns	2,441	68	—	1,012	—
Tuscany	2,299	9	—	—	—
Papal Territories	2,106	3	—	—	—
Western Africa	1	—	9,596	—	—
British India	1	2	17,459	56	—
Australia	977	540	1	4	—
British North America	578,748	468,572	9	45,614	14,813
British Guiana	4	19	4	103	—
United States	13,832	839	—	13,309	—
Miscellaneous	1,002	491	633	36	57
TOTAL LOADS	817,909	809,783	27,702	79,917	37,800

In the year ending 5th January, 1853, the quantity of timber imported and entered for home consumption was as follows:—

	Imported.	Entered for Home Consumption.
Timber and wood: battens, batten-ends, boards, deals, deal-ends, and plank, foreign ... *great hundred*	12	—
Deals, battens, boards, or other timber or wood, sawn or split:—		
Of British Possessions ... *loads*	572,401	571,281
Foreign ... *loads*	550,324	551,608
Staves ... *loads*	86,799	free.
Timber or wood, not being articles sawn, or split, or otherwise dressed, except hewn, and not otherwise charged with duty:—		
Of British Possessions ... *loads*	584,250	582,975
Foreign ... *loads*	341,319	391,512

Name.	Place of growth.	Weight per cubic foot.	Specific gravity.	Remarks.
		lb. oz.		
Abies excelsa (spruce fir)	Oxfordshire	27 2	·434	Used for scaffold-poles, ladders, common carpentry, &c.
Acer campestre (maple)	Oxfordshire	37 1	·593	Used for ornamental work when knotted; it makes the best charcoal, and turns well.
Acer pseudo-platanus (sycamore)	Wandsworth	34 11	·555	Used in dry carpentry, turns well, and takes a fine polish.
Æsculus hippocastanum (horse-chestnut)	Wandsworth	24 2	·386	Used for inlaying toys, turnery, and dry carpentry.
Alnus glutinosa (alder)	Oxfordshire	23 8	·376	Used for common turnery-work, &c.; and lasts long under water, or buried in the ground.
Arbutus unedo (Arbutus)	Killarney	45 6	·726	Hard, close grained, and occasionally used by turners.
Berberis vulgaris (barberry)	. . . .	37 11	·603	Used chiefly for dyeing.
Betula alba (common birch)	Epping	34 14	·558	Inferior in quality, but much used in the north of England and Scotland for staves for herring barrels.
Carpinus Betulus (hornbeam)	Epping	40 5	·645	Very tough, and makes excellent cogs for wheels; forms a good charcoal, and is much valued for fuel.
Castanea vesca (chestnut)	Cornwall	36 7	·583	Used in ship-building, and is much in repute for posts and rails, hop-poles, &c.
Cedrus Libani (cedar of Lebanon)	. . . .	38 13	·621	Used for furniture, and sometimes for ornamental joinery work.
Cerasus vulgaris (common cherry)	. . . .	33 3	·531	Excellent for common furniture, and much in repute; works easily, and takes a fine polish.
Corylus Avellana (common nut)	. . . .	36 0	·576	The young wood is used for fishing-rods, walking-sticks, &c.
Cratægus oxyacantha (white-thorn)	Epping	45 14	·734	Hard, firm, and susceptible of a fine polish.
Cupressus sempervirens	Mortlake	34 10	·554	Fine grained, and fragrant; very durable.
Cytisus laburnum (common laburnum)	Oxfordshire	45 9	·729	Hard and durable, and much used by turners and joiners.
Euonymus Europæus (lance-wood)	. . . .	34 0	·544	Wood used for skewers, and is hard and fine grained.
Fagus sylvatica (common beech)	Oxfordshire	41 2	·658	Much used for common furniture, for handles of tools, wooden vessels, &c. &c., and when kept dry is durable.
Fraxinus excelsior (common ash)	Oxfordshire	36 11	·587	Very tough and elastic; is much used by the coachmaker and wheelwright, and for the making of oars.
Ilex aquifolium (holly)	. . . .	41 9	·665	The best white wood for Tunbridge-ware; turns well, and takes a very fine polish.
Juglans regia (common walnut)	Sussex	36 1	·577	Used for ornamental furniture, much in repute for gunstocks; works easily.
Larix Europæa (larch)	Oxfordshire	35 0	·560	Used in house-carpentry, and for ship-building; is durable, strong, and tough.
Morus nigra (common mulberry)	Mortlake	41 5	·661	Sometimes used for furniture, and by turners, but is of little durability.
Pinus picea (silver fir)	. . . .	23 2	·370	Used for house-carpentry, masts of small vessels, &c.
Pinus sylvestris (pine)	Oxfordshire	24 5	·389	Much used for rafters, girders, and house-carpentry.
Platanus orientalis (plane)	Wandsworth	39 12	·636	An inferior wood, but much used in the Levant, for furniture.
Populus alba (Abele)	. . . .	27 11	·443	A light soft wood, of little value.
Populus dilitata (Lombardy poplar)	. . . .	21 13	·349	Soft and spongy, rapidly decaying, unless kept dry.
Prunus domestica (damson)	Wandsworth	45 8	·728	Hard and fine grained, but not very durable; used for turning, &c.
Prunus laurocerasus (laurel)	. . . .	46 14	·750	Hard and compact, taking a good polish.
Prunus spinosa (blackthorn)	Oxfordshire	43 11	·699	Hard, capable of a fine polish, but apt to split.
Pyrus aucuparia (mountain ash)	Yorkshire	38 6	·614	Fine grained, hard, and takes a good polish; used in turnery, and for musical instruments.
Pyrus communis (Burgamot pear)	Bermondsey	38 9	·617	Strong, compact, and close grained; used for turning handles to tools, &c., and takes a good black dye.
Pyrus malus (crab)	Yorkshire	45 6	·726	Hard, close grained, and strong.
Pyrus sorbus (service tree)	Epping	46 11	·747	Hard, fine grained, and compact; much in repute by millwrights for cogs, friction rollers, &c.
Quercus ilex (evergreen oak)	Wandsworth	47 5	·757	Wood very shaky when aged; is durable and strong, and makes an excellent charcoal.
Quercus pedunculata (English oak)	Sussex	39 0	·624	This oak is much esteemed for ship-building; the strongest and most durable of British woods.
Quercus sessiliflora (Welsh oak)	. . . .	37 11	·603	A good wood for ship-building, said to be inferior to the common oak.
Robinia pseud-acacia (common acacia, locust)	Epping	44 1	·705	Much used for treenails in ship-building, and in the United States is much in repute for posts and rails.
Salix alba (white willow)	Surrey	24 14	·398	Used for toys, and by the millwright; is tough, elastic and durable.
Salix caprea (palm sallow)	Oxfordshire	24 8	·332	Tough and elastic; is much used for handles to tools, and makes good hurdles.
Salix fragilis (crack willow)	Oxfordshire	32 0	·392	Light, pliant, and tough; is said to be very durable.
Taxus baccata (yew)	. . . .	41 9	·665	Used for making bows, chairs, handles, &c.; the wood is exceedingly durable, very tough, elastic and fine grained.
Tilia Europæa (common lime)	Wandsworth	27 3	·435	Used for cutting blocks, carving, sounding-boards and toys.
Ulmus campestris (English elm)	. . . .	30 9	—	Used in ship-building, for under-water planking, and a variety of other purposes, being very durable when kept wet or buried in the earth.
Ulmus montana (wych elm)	Oxfordshire	35 14	·574	Considered better than common elm, and is used in carpentry, ship-building, &c.

The various methods of jointing timbers are described under CARPENTRY—BRIDGE, Sec. iv.—SHIP, &c. MARINE GLUE, patented by Mr. Jeffery in 1842, possesses very powerful cementing properties. It is formed by dissolving 1 lb. of caoutchouc in small pieces in 4 gallons of coal naptha with frequent stirring, the solution occupying 10 or 12 days. 2 parts shell-lac are then fused in an iron vessel, and 1 part of the solution being stirred well in, the glue is poured out on slabs to cool. When two pieces of wood are glued or cemented by its means, the joint becomes stronger than the fibres of the wood itself. Large masts being formed of pieces cemented or jointed together, it has been proposed to Mr. Jeffery to employ his marine glue for this purpose; but, from a Report made to the Admiralty, by a board of Dock-yard Officers, in 1843, it appears that this glue is even *too good* for the purpose; if any part of a mast decays, it is customary to take the mast to pieces, and re-employ all the sound pieces; but it was found that a mast which had been formed by the aid of the marine glue was with such difficulty separated, that the pieces were scarcely available again. The marine glue also constitutes an excellent substance for pitching or paying the seams of ships. An inferior but strong marine glue is formed by simply dissolving shell-lac in naphtha.

We next proceed to notice a few points connected with the chemistry of wood.

When fine saw-dust is boiled, first in alcohol, then in water, next in a weak solution of potash, afterwards in dilute muriatic acid, and lastly, several times in distilled water, so as completely to remove all the soluble portions; the substance which remains when dried at 212° is called *lignin;* it forms the skeleton of plants and the basis of their structure; it varies in texture from delicate pith to the hard shells of seeds: it forms the bulk of such manufactured products as linen, cotton, and paper, and the washed and bleached fibre of hemp or flax is a good example of it. Pure lignin has a specific gravity of 1·5: it is white, tasteless, and is not soluble in water, alcohol, ether, or oils.

In Sweden and Norway saw-dust is sometimes converted into bread, for which purpose beech, or some wood that does not contain turpentine, is repeatedly macerated and boiled in water, to remove soluble matters, and is then reduced to powder, heated several times in an oven, and ground: in this state it is said to have the smell and taste of corn-flour. It has a yellowish colour, and ferments on the addition of leaven, the sour leaven of corn-flour answering best for the purpose. When well baked, it makes a uniform and spongy bread. By boiling wood-flour in water, a thick nutritious jelly is formed, like that made with wheat-starch.

Lignin is chiefly employed in nature in the organization of cells and vessels, and the solid parts of all plants. It must be distinguished from *ligneous* or *woody tissue,* which consists of *cellulose* together with other substances which encrust the walls of the membranous cells and give stiffness to the plant. When woody tissue has been repeatedly boiled in water and alcohol, so as to get rid of colouring matter and resin, it is found to contain an excess of hydrogen above that required to form water with its oxygen, and it also contains a little nitrogen. Pure cellulose is a ternary compound of carbon with the elements of water, and is said to be isomeric with starch, $C_{12}H_{10}O_{10}$. Hence, wood appears to be composed of two parts; *first,* lignin, which forms the walls of the vegetable cells, and, *secondly,* cellulose, which fills the cells and forms an incrustation on their walls. Lignin dissolves in strong nitric acid; cellulose remains undissolved. Sulphuric acid dissolves cellulose, without blackening it, and converts it into a nearly colourless adhesive substance, soluble in water, and agreeing in its characters with dextrine. Lignin, separated from cellulose, is said to contain $C_{35}H_{24}O_{20}$. The action of nitric acid on lignin is more particularly noticed under GUN-COTTON.

The conversion of cellulose into dextrine is the fundamental fact in the process of converting old rags into more than their weight of sugar. This is one of those marvels of chemistry which has taken possession of the popular mind, and it may be well to notice it further in this place, and to state that, however valuable this fact is in a scientific point of view, the materials are too costly, and the process is too tedious, to make it commercially valuable; although we have seen, under the article GUM, that dextrine or British gum is made on a large scale for the purposes of the manufacturer. To make sugar from old rags, concentrated sulphuric acid is to be slowly added to half its weight of lint or linen, in small pieces, carefully avoiding any rise in temperature, which would produce charring or blackening. When the proper quantity of acid has been added, the mixture is triturated in a mortar and left to stand for a few hours. It is next rubbed up with water, warmed, and filtered, in order to separate any small portions of insoluble matter that may be present. The solution may now be neutralized by means of chalk, and again filtered. The gummy liquid contains lime, partly as sulphate, and partly in union with a peculiar acid, the *sulpholignic,* which is composed of the elements of sulphuric or hypo-sulphuric acid, in combination with those of lignin. If the liquid, before it is neutralized, be boiled for three or four hours, and the water be replaced as it evaporates, the dextrine becomes entirely changed into grape-sugar.

Wood is very valuable as a fuel: the excess of hydrogen contained in it which, in burning and forming water, requires for equal weights three times as much oxygen as the carbon does in forming carbonic acid, gives out in burning nearly four times more heat than the carbon.

The chemical changes required for the conversion of wood into coal are noticed under COAL.

When wood is subject to destructive distillation, a number of complicated products are formed, varying with the nature of the wood and the temperature. If the wood contain resin, some of those substances

described in the process for making resin gas [see GAS] will pass over. If the wood contain azotised principles, ammonia will be formed. If the object of the distillation be chiefly for the sake of the charcoal, white woods are placed in iron retorts, which are gradually heated to redness. The volatile products consist of gases and vapours: among the former are carburetted hydrogen, carbonic acid, carbonic oxide, &c. The vapours condense into liquid or solid products; some of the liquids are soluble in water, such as *pyroxylic spirit*, *pyroligneous acid*, &c, and the insoluble products forming tar and certain oily substances. [See TURPENTINE.]

The pyroxylic or wood-spirit thus obtained is an important substance. It resembles alcohol in its affinities, forming an ether and a series of compounds exactly corresponding with those of the vinous spirit. Like alcohol, wood-spirit is regarded as a hydrated oxide, of a body corresponding with ethyle [see ETHER]; and which, like that body, has not been isolated; it is called *methyle* (from μήθυ wine, and ὕλη wood); it contains C_2H_3, and its symbol is ME. The following table contains a few of the compound methyle ethers, and the resemblance between this table and the one given under ether will appear very striking:—

WOOD-SPIRIT SERIES.

Methyle	C_2H_3
Oxide of methyle	C_2H_3,O
Chloride of methyle	C_2H_3,Cl
Iodide of methyle	C_2H_3,I
Wood-spirit	$C_2H_3,O+HO$
Sulphate of oxide of methyle	$C_2H_3,O+SO_3$
Nitrate of oxide of methyle	$C_2H_3,O+NO_5$
Sulphomethylic acid	$C_2H_3O,2SO_3+HO$
Formic acid	C_2HO_3
Chloroform	C_2HCl_3

Hydrated oxide of methyle (Me O + HO). *Pyroxlic* or *wood-spirit* is contained in the acid liquor or wood-vinegar produced by the distillation of wood, and is separated by distillation, the first portions which pass over being set aside. The acid liquor does not probably contain more than one per cent. of the spirit. A portion of the acid liquor of course comes over with the spirit, and this is neutralized by means of hydrate of lime, and the clear liquor separated from the oil which floats on the surface, and from the sediment at the bottom of the vessels, and is again distilled. In this way is procured a volatile liquid which burns like weak spirits of wine; but it may be strengthened like ordinary spirit by rectification, and made pure and anhydrous by distilling it from quick-lime at the heat of a water-bath. When pure, wood-spirit is a thin colourless liquid, with a peculiar odour, unlike that of alcohol, and it has a hot disagreeable taste; it boils at 152° F., its density is ·798 at 68°, and the density of its vapour is 1·12. Wood-spirit mixes freely with water, and, like alcohol, dissolves the resins and volatile oils, and is often a cheap substitute for spirits of wine for that purpose. It may also be burnt in a spirit-lamp, but it emits a peculiar odour, which is apt to produce headache.

Oxide of methyle, MeO, or wood ether, is obtained by the following process:—One part of wood-spirit and four parts of concentrated sulphuric acid are mixed together in a flask, and a gentle heat applied; the mixture blackens, and a large quantity of gas is evolved, which may be passed through a solution of potash and collected over mercury; this gaseous substance is the ether in question; it does not liquefy at so low a temperature as 3° F.; it has an ethereal odour, and burns with a pale flame. It is soluble to a certain extent in water, and to a larger extent in alcohol, wood-spirit, and strong sulphuric acid. Its density is 1·617.

Chloroform has been noticed in a separate article. [See CHLOROFORM.] The interest which attaches to the other members of the methyle group is purely scientific. When wood is treated for the production of pyroligneous acid, or wood-vinegar, about 8 cwt. of dry hard wood is enclosed in a cast-iron cylinder, about 6 feet long and 4 feet in diameter, and set up on end: the charge of wood is introduced at the bottom or mouth of the retort, which is then closed by a cast-iron plate, secured by wedges, and made air-tight by a clay-luting. To the top is screwed an iron plate, from the centre of which proceeds a tube for conducting the products of distillation through a condensing or refrigerating apparatus, the main tube of which varies from 9 to 14 inches in diameter, and receives the products of a number of similar cylinders. The cylinders are contained in a furnace which is left to burn for some hours. About 35 gallons of pyroligneous acid are produced from one charge of wood: it is of a deep brown colour, and contains much tar; its density is 1·025. It is rectified by a second distillation in a copper still. In rectifying 100 gallons of the crude acid, about 20 gallons of a thick tarry substance remain in the still, and the distillate is a limpid brown vinegar, having an empyreumatic smell, and of the density of 1·013. To purify this vinegar it is saturated with cream of lime, with which much of the empyreumatic extractive combines in an insoluble form; after which the clear solution containing acetate of lime is decanted, and is treated with a solution of sulphate of soda, which throws down an insoluble sulphate of lime, while the acetic acid combines with the soda and remains in solution. This is drawn off, the sulphate of lime is washed, and the solution of acetate of soda evaporated to a certain point, during which a quantity of empyreumatic resin forms on the surface, and is skimmed off. The solution is now set aside to crystallize: the mother liquor is subjected to a special treatment, until it at length contains nearly all the remaining empyreumatic matter combined with the soda. It is lastly removed by calcination, and the soda recovered. Any remaining empyreumatic matters in the crystallized product are also got rid of by careful calcination, in some cases, after a second solution and re-crystallization. After the calcination the salt is again dissolved and crystallized, and forms pure acetate of soda, which is distilled with 0·36 of its weight of sulphuric acid. The product, which is received in silver condensers, is a strong vinegar of the density of 1·05, which, how-

ever, still has an empyreumatic taint, which is finally removed by animal charcoal. It is diluted with water, and if intended for the table is coloured with burnt sugar, and a pleasant odour imparted to it by means of a few drops of acetic ether. It is used in the arts as a general substitute for wine-vinegar. It is employed in pickles and sauces in a stronger state than common vinegar, and in too many cases the nauseous empyreumatic flavour (which is removed with so much difficulty) is but too perceptible.

WOOD ENGRAVING. See ENGRAVING.

WOOF. See WEAVING.

WOOL. The property of the fibres of wool to *felt* or mat together into a kind of cloth must have attracted notice at an early period. The fitness of the woollen fibres for spinning into yarn, and for weaving the yarn into a superior kind of cloth to that produced by felting, must also have been observed almost as soon as man became acquainted with wool-bearing animals. The spinning and weaving of wool was well known in the time of Moses; they were extensively practised by the ancient Greeks and Romans; and when the latter people made the conquest of Britain, they probably introduced these arts into the island; and the inhabitants thus came gradually to exchange the most primitive form of clothing—namely, that of the skins of animals caught in the chase—for a more artificial and more convenient description of covering. The Romans appear to have had a factory at Winchester for supplying cloth to the Roman army. The natives of Britain, however, adopted the new art very slowly, the peasants continued to use garments of leather, and did so to a much later period, for the "buff-jerkin" was in use among the labouring population at the time of the Commonwealth.

The first mention of the sheep in Britain occurs in a public document of the date 712, in which the price of a sheep is fixed at one shilling until a fortnight after Easter. We read also that the mother of Alfred the Great was skilful in the spinning of wool, and instructed her daughters therein. At later periods the art of spinning wool was considered part of a good education; and the term *spinster*, as applied to unmarried females, indicated the nature of their principal occupation. [See WEAVING.] The origin of the woollen manufacture as a national employment is supposed to date from the time of William the Conqueror, when a number of Flemings, being deprived of their territory by an incursion of the sea, came to England and endeavoured to obtain the patronage of the Queen, who was a native of their country. In this they were successful, and they were established under royal patronage along the northern frontier, in the neighbourhood of Carlisle. Henry I., however, finding that they did not agree with his other subjects, removed them to a district taken from the Welsh, now forming part of Pembrokeshire. Henry II. granted a fair for clothiers and dressers, to be held in the churchyard of Bartholomew Priory for three days—a spot still designated the Cloth Fair. Towards the end of this reign the manufacture extended to several parts of the kingdom, and companies of weavers were formed in the counties of York, Oxford, Nottingham, Huntingdon, Lincoln, and also at Winchester, which paid fines to the King for the privilege of carrying on their trade, to the exclusion of other towns. There were also dealers who paid fines to the King for permission to buy and sell dyed cloth. Henry II. confirmed the weavers of London in their guild, and prohibited the use of Spanish wool under pain of forfeiture of the goods. The troubles of succeeding reigns diminished the prosperity of this trade; but it again revived in the reign of Edward III., when one Kemp of Flanders was licensed to settle at Kendal, in Westmoreland, where his descendants are still said to practise the trade of their ancestors. The cloth called "Kendal green" became celebrated. The success of Kemp led the sovereign to invite others of his industrious countrymen to settle in England, and the prosperity consequent on the extended employment of the poor thereby is a subject of congratulation in Fuller's Church History. We learn that the result of this wise measure, combined with the trade already existing, was—the production of woollen fustians at Norwich; baizes at Sudbury; broad cloths in Kent; kerseys in Devon; friezes in Wales; cloths in Worcestershire, Gloucestershire, Hampshire, Sussex, and Berkshire; coarse cloths in the West Riding of Yorkshire; and serges at Colchester in Essex, and Taunton in Somersetshire. A celebrated Dutch cloth-maker in Gloucestershire had the surname of *Web* bestowed upon him by Edward III. About this time the use of Fuller's-earth in this manufacture was discovered. The cruelty of the Duke of Alva drove over from Holland a number of industrious Dutch, who increased the prosperity of the woollen trade of this country. The wool trade was the subject of frequent and contradictory legislation during the reign of Edward III. A law was first passed forbidding the exportation of British wool, and the importation of foreign cloth. A tax of 20*s.* was levied on every sack of wool employed in the home manufacture. After some years, however, at the joint entreaty of the grower and manufacturer, wool was again allowed to be exported, and foreign cloth imported on payment of a tax. British wool at this time was so much esteemed that it sold at very high prices in foreign markets, and was often used instead of money; thus, at a time when gold was scarce, in 1342, the king sent a large number of sacks of wool to Cologne, to redeem Queen Phillippa's crown, which was pawned there for 2,500*l.* As the trade increased, a sworn officer, called an *alnager*, was appointed to inspect woollens, and to prevent imposition.

Restrictions were again put on the exportation of wool in the reign of Richard II. These caused great murmurings, so that the restrictions were removed; but British wool did not recover its former high price. Spanish wool began to be extensively employed in broadcloths, and a peculiar class of goods called *worsted* (from the name of a small town in Norfolk, where they were first made,) also came into

fashion. The taste for long wool, or worsted goods, led to variations in the growth of wool, and to changes, if not deteriorations, in the native breeds of sheep. The long-wooled sheep of this country soon became celebrated, and the fleece was in much request abroad. Attempts were also made to export the animal itself, but this was forbidden by laws passed in the reigns of Henry VI. and Elizabeth, under very heavy penalties. This frequent and mischievous legislation on the subject of our staple trade was rendered ridiculous by the sovereigns themselves being the first to infringe the regulations respecting the exportation of the sheep. Thus, Edward IV. sent a present of Cotswold rams to Henry of Castile, and another flock to John of Aragon. It is also said that the celebrated breed of Spanish sheep, called *Merino*, obtained this name from *Marino*, because they were originally imported *by sea* from England, in the reign of Henry II. Edward IV. also granted to his sister Margaret, Duchess Dowager of Burgundy, permission to export yearly from England, free of all duty, 1,000 oxen and 2,000 rams to Flanders, Holland, and Zealand. In the reigns of Henry VII. and Henry VIII. the wool trade was in a declining condition; the British short wool did not maintain its old reputation either at home or abroad. Still there were a few celebrated manufacturers, whose wealth and importance may be judged of by the fact that one of them, John Winchcombe (better known as Jack of Newbury), kept 100 looms constantly at work, and fitted out at his own cost 60 soldiers for the battle of Flodden Field.

The system of monopolies established in the reign of Henry VIII., which restricted the manufacture of certain articles to particular towns, was very injurious to the woollen trade. Thus, it was declared by law that the manufacture of coverlets should be confined to the city of York, worsted to the city of Norwich. The manufacturers of Worcester were in like manner limited to that town, with four others.

The invention or introduction of the spinning-wheel, about the year 1530, caused some revival of the woollen trade, towards the end of the reign of Henry VIII.; and in the reign of Elizabeth, the trade shared in the general prosperity of the kingdom. This judicious sovereign permitted the grower of wool to select his own market for its disposal, and left the trade as unfettered as possible, judging correctly that the various raw and manufactured products would, if left to themselves, become diffused by natural channels, and thus contribute to the prosperity of the people, and the consequent strength of the government. In singular contrast with this liberal policy was that of the Spanish government in the Netherlands: religious persecution drove from their country many thousands of industrious artisans, who sought refuge in London, and various parts of England, and enriched our land by their skill and industry; their improved machines, and superior methods in the manufacture of wool and silk, enabling us to send into the market better fabrics than heretofore. There were marked improvements in the manufacture of light cloth and worsteds, in which England had hitherto been deficient; and new markets were opened for the increased produce.

Although the English were skilful in the weaving and dressing of cloth, yet the art of dyeing and finishing it, once well known to them, had been lost amidst the distractions of the kingdom. It was therefore the custom to send white cloths into Holland to be dyed and dressed. In the reign of James I., some English merchants and manufacturers proposed to undertake these operations on certain terms, leaving to the king the monopoly of the sale. This plan was tried, but did not succeed; the natural result of the absence of competition being, that the cloths were badly dyed, and the expense was greater than that of sending them abroad, so that the Hollanders still continued to finish our cloths as before. But in the year 1667 a dyer, named Brewer, came from the Netherlands, with his workmen, and, under the patronage of the government, instructed the English manufacturers in his art, so that they soon became independent of the continent in this respect. During the civil wars of Charles I. the trade escaped from the hands of the English into those of our continental rivals, and various descriptions of cloth were manufactured by them which had previously been the sole produce of England. In order to revive the trade, one of those absurd laws was passed, which show so much ignorance of the principles of commerce on the part of the legislature. In 1666 it was enacted that every person should be buried in a shroud, composed of wool alone, under the forfeiture of 5*l.* to the poor of the parish. This law continued in force about 150 years. In the year 1685, that most unjust law, commonly known as the revocation of the edict of Nantes, was passed in France, whereby upwards of 600,000 Protestants, being deprived of the liberty of worshipping God according to the light of Scripture truth and of their own conscience, were compelled to expatriate themselves. Of this large number, no less than 50,000 sought refuge in England, where they were well received. Many of them were skilful in the manufacture of cloth, and improved the lighter textures, which at that time were in great demand. A larger supply of fine cloth was produced, a greater number of sheep were bred, and the trade generally revived. From that time to the present, the woollen trade has continued steadily to increase in prosperity. Some remarkable changes, however, have taken place in the supply of the raw material. The system of turnip husbandry was found to be highly beneficial to the rearing of sheep, for by its means a regular supply of food was secured to the flocks at all seasons. The increased demand for wool was thus met by a large increase in the number of sheep, which had risen from 12,000,000 in 1698, to 32,000,000 in 1833. It was found, however, that the fattening and increased growth of the animal, consequent on the new system of husbandry, was not favourable to the texture of the wool; for as the sheep increased in size, the fibre of the wool became longer and coarser. Thus the goods manufactured from it became deteriorated in

quality, and ceased to find a sale in their accustomed markets. By a natural reaction, the farmer could no longer sell his wool, and he soon complained loudly against the Spanish and other foreign wools which the manufacturer preferred to his own. As the government of this country has ever been disposed to lend an attentive ear to the complaints of the landowner, British wool was accordingly *protected*, although that protection involved the ruin of the woollen-cloth manufacturer, and consequently of the wool-grower. This result was happily prevented by the discovery that British wool, although changed in character, had acquired properties which eminently fitted it for another branch of the trade. The wool had no longer that short fibre which fits it for *carding*, but a long fibre which well adapts it for *combing;* so that if no longer fitted for the manufacture of broadcloth, it was well adapted to that of worsted. On this discovery, the government removed the fetters which had so long and so variously impeded this branch of industry. In the course of years an important export trade arose in British wools and worsted, while the imports of wool from Spain and Germany rose from 3,000,000 lbs. in 1800, to 91,692,864 lbs. in 1852; while the introduction of cotton machinery, in a modified form, was of great importance to the manufacturing processes.

Wool is defined by Professor Owen to be "a peculiar modification of hair, characterised by fine transverse or oblique lines, from 2,000 to 4,000 in the extent of an inch, indicative of a minutely imbricated scaly surface when viewed under the microscope, on which, and on its curved or twisted form, depends its remarkable felting property, and its consequent value in manufactures." Wool is not peculiar to the sheep; but forms a sort of under coat, beneath the long hair, in the goat and many other animals. The Argali, or wild sheep of Siberia and Kamtschatka, has a summer coat of hair, sleek as that of the deer; but in winter, a woolly variety of hair is developed in excess, and the under coat is also of a fine woolly down. In the domestic sheep the fleece has been greatly improved and modified by circumstances of climate, pasture, shelter, and judicious crossing of breeds, by which many varieties of wool have been grown, chiefly divisible into the two great classes of *carding wool* and *combing wool.* The occurrence of hair in the fleece of the domestic sheep is now rare and is considered as indicative of bad management; but if sheep are left to themselves on downs and moors, there is a tendency to the formation of hair among the wool. Change of pasture has a marked influence on the quality of the wool: if sheep that have been fed on chalk downs be removed to richer pastures only a month before shearing, a remarkable improvement will take place in the fleece. So also sheep that occupy lands within a few miles of the sea will produce a longer and more pliant wool than that of sheep from more inland districts. Wool varies in quality, in the same flock, at different times. When the sheep is in good condition, the fibre is brilliant; but in badly fed or diseased sheep the wool is dull and dingy, and when cut from the dead animal it is harsh and weak, and takes the dye badly. In commerce wools are distinguished as *fleece* wools and *dead* wools—the first being obtained from the annual shearings, the second from the dead animal.

The once celebrated merino wool, is obtained from the migratory sheep of Spain. Some years ago, it was calculated that the number of these migratory sheep amounted to 10,000,000. Twice a year, in April and October, they are led a journey of about 400 miles, passing the summer in the mountains of the north, and the winter on the plains towards the south. The excellence of the wool, to which everything else is sacrificed, is supposed to be due to an equality of temperature maintained by shifting the position of the sheep, so that they may occupy the cooler mountains in summer, and the warmer plains in winter. An objection to this explanation arises from the fact, that the fleece of some of the German merinos, which do not travel at all, is far superior to the best Leonese fleece; and, even in Spain, it is said that there are stationary flocks which produce wool equal in quality to that of the migratory ones. The first impression made by the merino sheep, on one unacquainted with its value, would be unfavourable. The wool lying closer and thicker over the body than in most other breeds of sheep, and being abundant in *yolk*,[1] is covered with a dirty crust, often full of cracks. There is also a coarse and ugly patch of hair on the forehead and cheeks, which is cut away before shearing time. There is also a singular looseness of skin under the throat, giving a remarkable appearance of hollowness in the neck. The pile, when pressed upon, is hard and unyielding, in consequence of the thickness with which it grows on the pelt, and the abundance of the yolk detaining all the dirt and gravel which fall upon it; but when examined, the fibre is found to exceed in fineness, and in the number of serrations and curves, that which any other sheep in the world produces. The average weight of the fleece in Spain is 8 lbs. from the ram, and 5 lbs. from the ewe. "The excellency of the merinos consists in the unexampled fineness and felting property of their wool, and in the weight of it yielded by each individual sheep; the closeness of that wool, and the luxuriance of the yolk, which enables them to support extremes of cold and wet quite as well as any other breed; the easiness with which they adapt themselves to every change of climate, and thrive and retain, with common care, all their fineness of wool under a burning tropical sun, and in the frozen regions of the north; an appetite which renders them apparently satisfied with the coarsest food; a quietness and

(1) The yolk is a peculiar secretion from the glands of the skin, and serves to nourish the wool, and by matting the fibres together forms a defence against wet and cold. It exists in greatest quantity about the breast and shoulders, where the best wool is produced. It differs in quantity in different breeds, but the medium quantity is about half the fleece, and this allowance is made to the buyer, when the wool is sold without having previously been washed. The yolk is a true soap, and is soluble in water; hence the practice of washing sheep previous to shearing. If the yolk be left in the fleece it is apt to ferment, and to make the wool hard and harsh.

patience into whatever pasture they are turned, and a gentleness and tractableness not excelled in any other breed." [1]

The periodical journeys taken by these sheep in Spain can be traced back to the middle of the 14th century, when a tribunal, called the Mesta, was established for their regulation, consisting of the chief proprietors of these migratory flocks, the king being the merino mayor. It established a right to graze on all the open and common land that lay in the way; it claimed also a path, 90 yards wide, through all the enclosed and cultivated country, and prohibited all persons, even foot passengers, from travelling these roads when the sheep were in motion. The flocks are divided into detachments of 10,000 each, under the care of a mayoral or chief shepherd, who has under him 50 shepherds and as many huge dogs. The mayoral precedes the flock, and directs the length and speed of the journey; the others, with the dogs, follow and flank the cavalcade, collect the stragglers, and keep off the wolves, which regularly follow at a distance and migrate with the flock. A few asses or mules carry the clothing and other necessaries of the shepherds and the materials for the fold at night. Several of the sheep are perfectly tamed, and taught to obey the signals of the shepherds. These follow the leading shepherd—for there is no driving—and the rest quietly follow them. The flocks travel through the cultivated country at the rate of 18 or 20 miles a-day; but in open country, with good pasture, more leisurely. Much damage is done to the country over which these immense flocks are passing; the free sheep-walk, which the landed proprietors are forced to keep open, interferes with enclosure and good husbandry: the commons also are so completely eaten down that the sheep of the neighbourhood are for a time half-starved. The sheep know as well as the shepherds when the procession has arrived at the end of its journey. In April their migratory instinct renders them restless, and if not guided they set forth unattended to the cooler hills. In spite of the vigilance of the shepherds, great numbers often escape. If not destroyed by the wolves, there is no danger of losing these stragglers, for they are found on their old pasture quietly waiting the arrival of their companions.

It is during this journey that the sheep are shorn, and the shearing time is an epoch of primitive oriental festivity. Buildings are erected at various places in the early portion of their journey: they are very simply constructed, consisting only of two large rooms, each of which will contain more than a thousand sheep; there is also a narrow, low, long hut adjoining, called the *sweating-house*. The sheep are all driven into one of these apartments, and in the evening those intended to be shorn on the following day are transferred into the hut. As many are forced into it as it will possibly hold, and there they are left during the night. In consequence of this close confinement they are thrown into a state of great perspiration; the hardened yolk is melted, and thus the whole fleece, by being rendered softer, is more easily cut. There is no previous washing nor any other preparation for the shearing. From 150 to 200 shearers are generally collected at each house, and a flock of 1,000 sheep is disposed of in a day. The sheep are turned back, as they are shorn, into the second apartment, and on the same or the following day continue their journey. Thus in the space of six days, as many flocks, each consisting of 1,000 sheep, pass through the hands of the shearers. The wool is then washed and sorted, and is ready for sale. The rams give most wool: three fleeces often averaging 25 lbs. When the sheep arrive at their summer pasture, salt is placed on flat stones, at the rate of about a hundred weight for every 100 sheep; this they lick eagerly, and it improves their appetite. They are always on the move in search of grass, which is scarce, for they will not touch thyme, which is abundant, and is left to the wild bee. They are never fed until the dew is dry, nor allowed to drink after hail-storms. In September the flocks are daubed with a red earth, which is said to conduce to the fineness of the wool. After their return in October the yeaning time approaches. The Merinos are not good nurses, so that nearly half the lambs, and in bad seasons, when the pasture fails, full three-fourths, are killed as soon as they are yeaned. The skins are sent to Portugal, and from thence to England, where they are used in the glove manufacture. The wool is soft and silky, and is formed in little rings or curls. March is a very busy month with the shepherds, who then cut off the tails of the lambs and the tips of the horns, that they may not hurt each other in their frolics; the shepherds also mark them on the nose with a hot iron. Forty or fifty thousand shepherds are said to be employed in tending these sheep. They are a singular race of men, almost as simple as their sheep. Their talk is almost entirely confined to rams and ewes; they know every one of the sheep, and the sheep know them. They live chiefly on bread seasoned with oil or grease; and though they sometimes procure mutton from their old or diseased sheep, it is not their favourite food. Their dress is a jacket and breeches of black sheep-skin; a red silken sash tied round the waist; long leathern gaiters; a slouched hat; a staff tipped with iron; and a *manta*, or brown blanket, slung over the left shoulder. When they have reached their journey's end, they build themselves rude huts, living generally a single life.

About the year 1765 the merino sheep was introduced into Saxony, and after some years became naturalised there: the breed of Saxon sheep was also improved by crossing, and after some years the Saxon fleece was found to be superior to the Spanish in fineness and manufacturing value.

In France the growth of wool has not been carried on with much success: sheep are numerous in the south, but the wools are long and coarse. In Sweden, Denmark, Prussia, and some other countries, the native breeds of sheep have been improved by the introduction of merinos; and so successful has this plan been in Hungary, that the fleece of that country

(1) Youatt on "The Sheep."

has rivalled that of Siberia and Saxony, and excelled the Spanish merino.

In the year 1787 a small flock of merinos from the borders of Portugal was received in England, but as they came from different districts, and were not uniform in character, no experiment was made with them. Application was made by George III. to the King of Spain, for permission to select sheep from one of the best flocks: this was granted, and a number of sheep of the valuable Negrette breed, which the law of Spain had hitherto prevented from being exported, arrived in England in 1791, and were transferred to Kew. In this, as in other cases, the experiments were successful. After a few crossings on the Wiltshires, the ewes became hornless; they had acquired the shape of the merino, the wool had increased from 3¼ lbs. to nearly 6 lbs. per fleece, and was scarcely inferior to that of the pure Spanish sheep. In England, however, as in other countries, the prejudices of the wool-grower opposed most serious obstacles to the diffusion of the merino. By the exertions, however, of scientific men, and the artificial stimulus of a "Merino Society," with Sir Joseph Banks as its president, with fifty-four vice-presidents, local committees in every county, public dinners and after-dinner speeches, the Negrette flock was regarded with favour and even with enthusiasm. At a public sale of merinos in 1810, a Negrette ram was sold for 173 guineas. All, however, would not do. The farmer found that it was more to his interest to grow mutton than to grow wool, and the system of artificial feeding enabled him to send his sheep to market within a comparatively short space of time; whereas the merinos fattened slowly, and were long in arriving at maturity. The increased value of the wool did not compensate for this disadvantage, and it was found that the finer foreign wool could be purchased at a cheaper rate than it could be grown in this country. The introduction of the merino into Australia was eminently successful. New South Wales had originally been supplied with sheep from Bengal, for the purpose of furnishing the colonists with mutton and wool, and of establishing a permanent flock; the climate was favourable to these sheep, but the fleece was coarse and hairy. They were much improved by the Southdown and Leicester varieties, and in a short time both the fleece and the carcase had doubled in value. In the year 1800 there were only about 6,000 sheep in the whole settlement. Shortly after a few merinos were imported from England, and the wool of the mixed breed was found to be equal to that of the pure merinos in Europe, while the wool of the pure breed also improved. The number of sheep rapidly increased; in 1813 it was upwards of 65,000; in 1817 it was 170,420; and in 1828 it was 536,391. As the fleece of the merino had become finer and softer in New South Wales, it was supposed that Saxony wool might be improved by transplantation. Accordingly some sheep were imported from Germany, and after a fair trial it was found that if the Saxon fleece had not been improved, it was superior to any that the colony had hitherto possessed. Australian wool is said to possess an extraordinary softness and silkiness, and spins well. The first importation of wool from New South Wales into England in 1807 was 245 lbs.: in 1848 it amounted to 23,000,000 lbs., of the value of upwards of 1,200,000*l.*

In the Great Exhibition, Germany retained its pre-eminence for fine wool. The fleeces exhibited by Messrs. Figdor and Sons, from Austria, presented in a high degree "the desired qualities of substance in the staple, and of fineness and elasticity of the component fibres, the spiral curves of which were close and regular, and were immediately resumed after being obliterated by stretching the fibre—the length of which was also considerable for wool of this carding quality, the most valuable for the finest descriptions of cloth."[1]

The worsted trade, although ancient,[2] did not begin to assume its present importance until about twenty years ago. The introduction of cotton machinery into this branch of manufacture took place towards the end of the last century; but up to the year 1834 worsted fabrics were made of wool alone, with the exception of bombazines and mixed fabrics manufactured in Norfolk; but at that time manufactures of worsted weft and cotton warp were first brought forward, and gave a great impetus to the trade. In 1836 the wool of the *alpaca*, an animal of the llama tribe inhabiting the mountain ranges of Peru, was introduced: this wool is of various shades of black, white, grey, brown, &c., and is remarkable for brightness and lustre, great length of staple, and extreme softness. After the difficulties of working this material had been overcome, the alpaca manufacture assumed an important rank in the worsted trade. About the same period, *mohair*, or goat's wool, from Asia Minor, came into general use in the West Riding of Yorkshire, and many beautiful fabrics were produced from it. The combination of silk with these new materials has led to the production of many beautiful fabrics for clothing and furniture; more rapid processes of manufacture have been contrived, improved machinery has been and is being constantly produced; and yet, notwithstanding the greatly increased facilities of production, the number of workpeople employed has been quadrupled during the last thirty years. Thus, Bradford, which is the centre of the manufacture, and the great market of this trade, had, in 1821, a population of 26,309; in 1831, 43,527; in 1841, 66,718; and in 1851, 103,782. At the commencement of the present century there were only 3 mills in Bradford, and there are now upwards of 160.

Section I.—Manufacture of Broad Cloth.[3]

Wool grown in England is but little used in he

(1) Jury Report, Class IV. Part ii.

(2) The invention of the wool-comb is assigned to St. Blaise: and the 3d of February, being the day of his canonization, was, until lately, kept as a festival in Bradford, and other parts of England.

(3) We are indebted for most of the details of this section to T. B. W. Sheppard, Esq., who has kindly furnished us with an outline of the processes, as carried on at the factory of the Messrs. Sheppard, of Frome, Somerset.

standard trade, *i. e.* the ordinary broad cloth manufacture. The principal demand for English wools is for flannels and coarse cloth, such as that used for coachmen's great-coats. The three varieties of wool principally employed in the manufacture of broad cloth are the *German wool*, the *Australian*, and the *Cape wool*. There are other wools which are more or less used, such as those from *Odessa* and *New Zealand*. German wool is the finest, and is used either alone or mixed with other wools for all the finest descriptions of cloth. Australian wool is divided into several varieties, the names being derived from the parts of the colony from which they are exported. *Sydney wool* is a good useful wool for common purposes, and obtains a price in the markets, from 1*s*. 4*d*. to 1*s*. 10*d*. per lb. Cape wool, from the Cape of Good Hope, is an inferior wool to the Australian, being usually much shorter in the staple, and more wasting or *smudgy*, as it is termed.

Wool comes to the English market in various states. Wools *in the grease* are such as have been shorn from the sheep in the natural yolk and dirt, and have not had anything else done to them. *Hand-washed wools* are such as have been taken from sheep which have been previously washed in running water. *Scoured* wools have been scoured and cleansed after being shorn, and these fetch the highest price in the market; but the German is of course more valuable than scoured Sydney. In purchasing wools, several points have to be considered in order to determine the value: the first great requisite is *fineness* of fibre, without which it is impossible to produce a fine cloth; *softness* is also an important quality, as much of the felting property of wool depends upon it. There must also be a certain *length* of fibre or staple; because, if this be too short, the wool will not spin out to the required degree of fineness. Length of fibre, however, is not of so much importance in wools for broad cloth as in those that are to be employed for making worsted goods. In estimating the quality of wools, the *waste* must also be considered. Few wools waste less than 3 lbs. per score, and some as much as 13 or 14 lbs. The purchaser has to consider the cleanliness of the wool and the quantity that it will waste in the various processes of manufacture, and must regulate his price accordingly. Greasy wools generally waste half their weight, and only fetch half the price that the same wools would if in handwashed condition. Various seeds become mixed with the wool, from the sheep rubbing themselves against bushes, &c. Of these, those known as *burrs* are the most detrimental, as it is very difficult to get them out of the wool, to which they attach themselves with such tenacity, that they actually become drawn out with the spun thread and woven in with the cloth. Other seeds, called *moits* and *hardheads*, are not so much to be guarded against as the former; but still, when present in any quantity, they are sufficiently prejudicial to lower the value of the wool. The great proportion of colonial wool is sold in London at quarterly sales, which were, till lately, held in the Hall of Commerce, in Threadneedle Street, but now take place in a building erected for the purpose in Moorgate Street, and are attended by buyers from all parts of the United Kingdom. The wools are put up in lots of from 1 to 8 or 10 bales, each bale or bag weighing from 2 to 3 cwt., or more. The wools of each day's sale are exposed to view at one or other of various large warehouses devoted to this purpose. The corner of every bag is cut open, and the lots are all marked on the bags. The buyer having his catalogue with him, examines and puts his valuation against the lots, and thus prepares for the sale, which commences at about four o'clock. The advance at each bidding is ½*d*., and the bidding is often very spirited. The following were the prices per lb. obtained for the various wools at the sales of March, 1854:—

	s. d.		*s. d.*		*d.*		*s. d.*
Sydney Fleece ...	1 6	to	1 10	Grease	7	to	0 11½
Scoured Sydney	1 10	to	2 2				
Port Phillip........	1 7	to	1 9½	Grease	7½	to	1 1
Cape..................	1 3	to	1 7	Grease	7	to	1 0½

Sorting.—After the bags of wool have been delivered at the manufactory, the first process which they undergo is that of *sorting*, or dividing into various qualities. This is an operation that requires great delicacy of touch and skill. The sorter, having opened the bag, takes each fleece, and lays it open before him on a table, sometimes formed of horizontal bars of wood, fastened together so as to form a sort of open framework, through which loose dirt can fall. The sorter divides the wool into various qualities, according to the fineness of the fibre. Three sorts, called respectively, *Primes*, *Seconds*, and *Thirds*, are generally sufficient for use.[1] When a certain quantity has been sorted, the sorter makes it up in loose bags, called sheets, ready to be sent to the dye-house.

Scouring, Dyeing, Willowing, and Oiling.—Before the wool is ready for dyeing, it requires to be *scoured* or washed, to get rid of the animal grease. This is done at the dye-house, with stale urine, heated to about 120°, and which is afterwards washed out in running water. The wool is now fit for dyeing, or it may be deferred until the cloth is woven: in the one case the cloth is said to be *wool-dyed*; and in the other *piece-dyed*. [See Dyeing—Indigo, &c.] It should, however, be stated that in the production of a black dye, the wool is boiled with bi-chromate of potash, and a small quantity of sulphuric acid; then washed in water, and treated with logwood, by which means a fast and solid black is produced. Instead of using logwood other dye-stuffs may be taken, by which means various other colours may be produced in a similar manner, for the oxide of chromium in the wool acts like alumina or per-oxide of iron in attaching colouring matters. In the Great Exhibition, Mr. Grune of Berlin exhibited prepared colours containing the mordant, by which it was stated that wool could be dyed at one operation with-

(1) Eight or ten divisions or sorts are sometimes made out of a fleece: these are called *prime, choice, super, head, downrights, seconds, fine abb, coarse abb, livery, short coarse*, or *breech wool*. The prime sort sometimes furnishes a few remarkably fine locks known as *pick-locks*.

out boiling. Some samples of well-dyed wool, illustrating the process, were also exhibited.

After the wool is dyed it is passed through the *Twilly Devil* or *Tucker*,[1] which consists of a large wooden cylinder having strong iron spikes, about 3 inches long, projecting from it, in a spiral direction round its circumference; this cylinder is enclosed in a wooden case, and the wool, supplied to it from an endless web or feeding-cloth, and passing between feeding-rollers, is exposed to the action of the spiked cylinder, which, revolving with great rapidity, tears apart the fibres of the wool and makes it *hollow* or light and open, at the same time allowing any dust or dirt to fall through a grating beneath. After this, it is necessary to pick over the wool in order to remove seeds, pieces of string, or other substances, and locks of wool of a different colour which have either not quite taken the dye, or belong to other lots of wool. This operation is performed by women, who sit before a low table, the top of which is formed of open wire-work, so as to allow dust to fall through; they examine all the wool, shake it open, and pick out all foreign substances. A good picker can pick about 20lbs. of wool per day. The expense and trouble of this process led to the invention, by Mr. Sykes, of Huddersfield, of the *woolpicking and cleaning machine*, also known as the *Burring Machine*, its great use being to free burry wool from the burrs, and it answers the purpose so well as to be gradually superseding the picking by hand.

The section, Fig. 2375, shows the principal working parts of the machine; A is the feed-cloth by which the wool is carried into the machine; *a a* are two fluted iron rollers which draw in the wool, and it is then exposed to the action of a heavy iron beater, B, which, rapidly revolving in the direction of the arrow, beats and separates the wool and throws it down on the cloth D, while dust and dirt pass through the

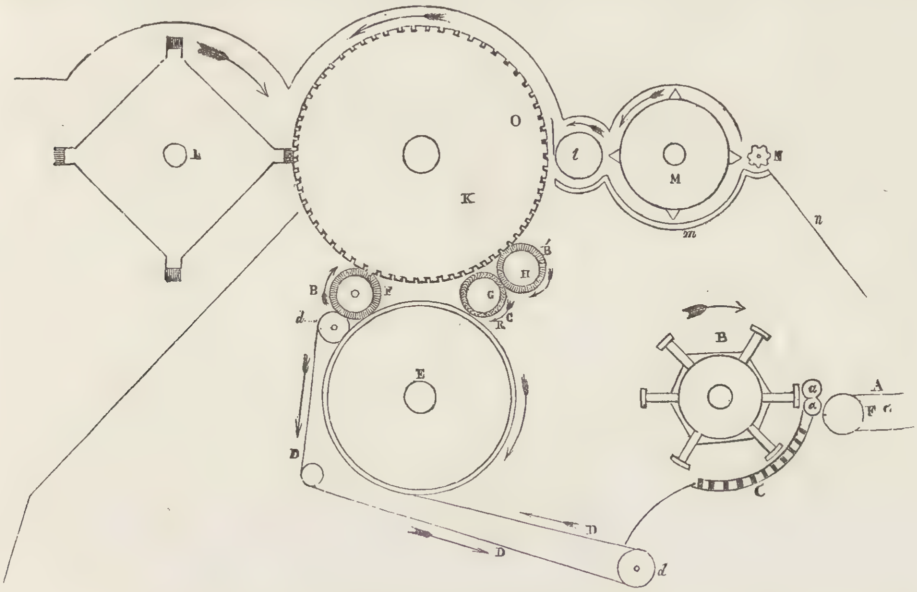


Fig. 2375. WOOL-PICKING AND CLEANING MACHINE.

grating C. The cloth D has a chain fastened to each side, the links of which work into studs on the rollers *d d*, thus ensuring regularity of motion; the loose wool is carried forward by this cloth under the wire cage E, which pressing upon it forms, it into a loose lap or fleece: this is taken off the cloth by the brush F, and transferred by it to the comb cylinder K. This cylinder consists of a number of fine iron combs, set longitudinally round the circumference of a circular wheel: by the revolution of this cylinder it is carried on to the card roller G, which takes it off the comb cylinder, and is itself stripped by the brush H, the latter returning the wool to the large cylinder, which then carries it forward to O. At O there is a steel blade or straight-edge placed vertically at a very small distance from the comb cylinder; the latter draws the wool through the narrow slit, but every burr, seed, or other foreign substance, is stopped by the plate O. A roller, *l*, covered with spiral blades, (similar to those used in the cutters) revolves against the plate O. This comes in contact with every burr, &c., that has been stopped by the plate, and knocks or throws it, with the lock of wool to which it is attached, back to the cylinder M, the short projecting points on which throw it back over the bars *m* of a grating to a small fluted wooden roller N, which finally throws back the lock of wool (from which generally the burr has now been detached) down the sloping board *n* on to the feed-cloth, where it passes into the machine with the other wool. The wool which has passed the opening at O is carried on by the combs till it is stripped off by the brushes fixed on the angles of a large square bar or prism L, which throw it out into

(1) The word *willy*, or *twilly*, is a corruption of the *willow* of the cotton manufacture, and this again is probably a corruption of *winnow*, the action of the machine being to separate impurities from the wool; but, according to some authorities, the first willowing machine was made of *willow-wood*, whence the name.

the room. This machine not only cleans the wool, but opens it, and renders it light and hollow, thereby fitting it for the scribbling process. It thus prepares about 50 lbs. of wool per hour.

After the wool has been picked, it is oiled previous to passing through the Scribbler and Carder. In order to do this, the wool is spread out on a stone floor, in a layer, to the depth of 6 inches or more. Either gallipoli or palm-oil is then sprinkled over it, by hand or by a kind of watering-pot; then another layer of wool is added, which is oiled as before, and so on in successive layers until the whole quantity of wool which is to be operated upon has been thus treated. From 3 to 4 lbs. of oil are used to every twenty pounds of wool; the wool is again passed through the Willy or Tucker, in order to mix the oil and wool thoroughly together. If the wool is picked by the Burring Machine, it is oiled previous to passing through it.

Scribbling and Carding.—The wool is now ready for the scribbler, which is very similar in principle to the Carding Engine described under COTTON, Figs. 638 to 644. Scribbling, however, is a coarser process than carding, and its object is to form the oiled wool into a broad thin fleece, or lap, in which the fibres are opened and separated. The wool goes through the scribbler always twice, sometimes three or four times, so that the fibres may be completely disentangled and separated. It is carded only once. The wool-carding engine differs somewhat from the cotton-carding engine. The fibres of wool being more twisted, elastic, and stiff than those of cotton, require the carding apparatus to be so arranged as not only to open the wool without breaking it, but also to make the fibres cross each other in all directions. The wool-carding engine consists of large cylinders or card-drums, surmounted by smaller cylinders called *urchins*, all covered with carding wires. The smaller cylinders, which are arranged in pairs, are of unequal size; the larger of the two is called the *worker*, and the smaller the *cleaner:* these revolve at great speed. At one end of the engine is an endless feeding-cloth, upon a certain length of which a given weight of the oiled wool is spread evenly by hand. This delivers the wool through a pair of feeding-rollers, which distribute it on the card-drum. From this the wool is

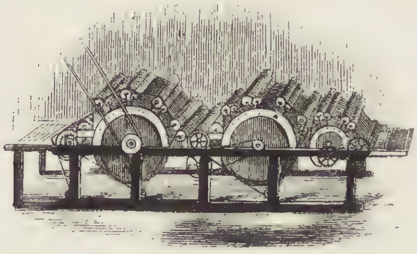


Fig. 2376. WOOL-CARDING.

gradually stripped by the first worker, whence it is received by the first cleaner, and by it again deposited in the large card-drum. When it has passed over the last cylinder into the drum, it is taken from it by a doffing-cylinder, from which the wool is removed by a steel comb, or doffing-knife, moving rapidly up and down. The doffing-cylinder is not entirely covered with wires, but merely with a succession of card leathers, arranged in straight bands, parallel to its axis, with spaces between every two bands. The effect of this arrangement is, that the doffing-knife removes the wool in the form of separate slivers, each the length of the doffing-cylinder, and these, instead of being wound upon a roller, fall into the plates of a plated cylinder, called the *roller-bowl,* which, being partly covered with a case or shell nearly in contact with it, the slivers are rolled into cardings, and are received upon an apron at the opposite end of the machine. The cardings are weighed from time to time, to see that each contains the proper quantity of wool.

Slubbing.—The rovings produced by the carder are the first commencement of the thread, though they possess little or no strength, being only held together by the interlacing of the fibres of the wool. In order to give strength, they require to be twisted. Some time after the introduction into the cotton manufacture of the Spinning Jenny, (see COTTON, Fig. 629,) an attempt was made to employ a similar machine in the preparation of woollen rovings, or *slubbings* as they are called, and which had previously been produced by hand on the spinning-wheel. The attempt succeeded, and the machine, under the name of the *Slubbing-Billy*, continues still in use for preparing the slubbings which are afterwards to be spun by the mule. The Slubbing-Billy consists of a wooden frame, within which is a carriage capable of being moved upon the lower side rails, through a space of several feet, called the *billy-gate*, from one end of the frame to the other. This carriage contains a number of spindles, which are made to rotate rapidly by a series of cords passing round the pulley of each spindle, and connected with a drum extending the whole breadth of the carriage, to which motion is given by the slubber turning the handle of the large wheel which is connected by a strap with the drum. The cardings are arranged upon a leathern or hempen apron, which is mounted, in a slanting direction, at the end of the

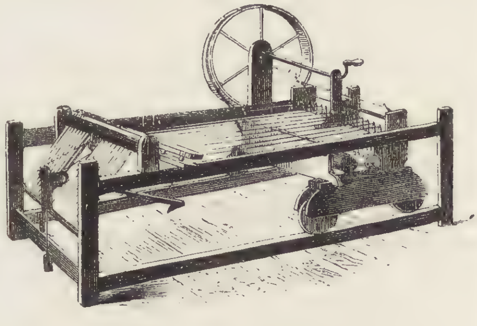


Fig. 2377. THE SLUBBING-BILLY.

frame, opposite to the moveable carriage. These cardings pass under a wooden roller, called the *billy-roller*, which presses lightly upon them, so as slightly to compress them. In front of this roller is a moveable rail, which, when it rests upon the cardings, pre-

vents them from being drawn through, and, when elevated, prevents the cardings from being drawn forward by the retiring of the spindle-carriage.

When the spindle-carriage is wheeled close up to the billy-roller, the clasp is opened by means of a lever, so as to release all the cardings. The carriage being then drawn a short distance from the clasp, pulls forward a corresponding length of the cardings; the clasp then falls down and holds the cardings firmly, while the carriage, continuing to recede, draws out and stretches that portion of the cardings which is between the clasp and the spindles. During this time the slubber keeps turning the wheel which causes the spindles to revolve, thus giving the cardings the proper degree of twist. This twist does not form yarn, for the slubbing has to be twisted in the contrary direction, when it is afterwards spun at the mule. Slubbings intended for warp yarn must be more twisted than those for weft. The inclined direction of the spindles gives to the cardings, or rovings, as they may now be called, a twisting motion, whereby they are continually slipping over the points of the spindles without getting wound upon them. When the rovings are properly twisted, the slubber winds them upon the spindles, by pressing down a faller-wire, so as to bear down the rovings from the points of the spindles, and place them opposite their middle part. He then makes the spindles revolve while he slowly pushes in the carriage, so as to wind the rovings upon the spindles in the form of conical cops. The cardings are so tender, that, if allowed to be dragged over the endless apron, they would be liable to break. The rollers upon which the apron is stretched are, therefore, made to revolve by means of two unequal weights attached to them by cords. When the carriage is pushed home, the heavier weight gets wound up; and, when the carriage is drawn out, this weight turns the roller and advances the endless apron, so as to deliver the cardings at the same rate as the carriage runs out. The cardings are brought from the carding-engines by children, who lay them over the left arm, and, by a slight lateral rolling motion of the fingers of the right hand, not easy to describe, join them on to the ends of the cardings on the apron. This is repeated as often as necessary, and, to prevent the improper thickening of the cardings at the juncture, each carding is smaller at the ends. Some little tact is required by the children to prevent any inequalities. They must be careful not to stretch the cardings in lifting them up, and must join them evenly and effectually. Unless these points are attended to, the slubbings form what are called "flies" or "ratched cardings." Unless all the ends are joined by the time the former cardings are drawn through, the ends are said to be "let up," and when this happens the work is considerably delayed.

It is surprising to notice the rapidity with which the piecening is performed; the fingers of the children become polished in a singular way by the constant handling of the oiled wool. "Children are preferable as pieceners, not simply from the cheapness of their labour, and the mobility of their muscles, but from their size, as they can work without constraint at the billy-board, which must be kept low for the convenience of the slubber, and could not be properly served by taller persons without painful and injurious stooping." It is usually calculated that one carding-engine will keep one billy with sixty spindles in active employment. One slubber should have two pieceners, so that each child has thirty cardings to manage.

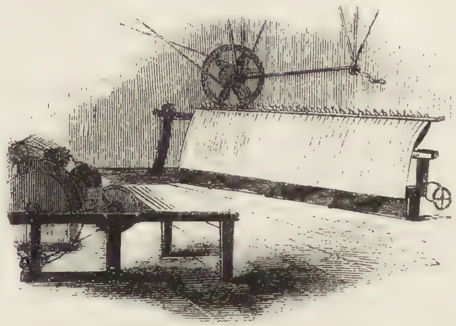


Fig. 2378. MODERN SLUBBING MACHINE.

When the yarn required is large for coarse purposes, the abb or shoot may be spun at once at the billy—twenties are the smallest that are thus spun. The slubbings are usually drawn to half the size that the yarn is to be. When thus spun, a thread of thirties, or 30 skeins to the pound, would be slubbed to about fifteens, or 15 skeins to the pound. The slubbings are then spun at the mule, Fig. 2378, which does not differ materially from the Cotton Mule. See COTTON, Fig. 664, and INTRODUCTORY ESSAY, p. cxlvi.

The Condenser, &c.—The operation of slubbing has been lately superseded in many mills by a machine called the *Condenser*. Where this machine is used, the scribbling-engines are thus arranged: the thin web or fleece is received upon a wooden cylinder, round which it winds as it is taken off the doffer by the comb. When it has wound round a certain number of times, a little mechanical contrivance rings a bell: this gives notice to the feeder to remove the web on the cylinder, which she does by running her finger along the surface of the cylinder in a line parallel to its axis. The web thus taken off is a thick sheet of scribbled wool, its length being equal to the circumference of the cylinder, and its breadth to the length of the cylinder. This web is taken to another engine and laid on the feed-cloth, which it just covers, and thus the feed of the wool is regular and not dependent on the care of the feeder. This second engine has the condenser attached to it. In place of the doffer there is a large cylinder, not covered with cards as the doffer would be, but having rings of card round it, each ring being about $\frac{3}{4}$ inch wide, and the distance between the rings about one eighth of an inch. Now, it is evident that the comb will remove not a continuous fleece, but a number of continuous strips of wool, each strip being $\frac{3}{4}$ inch wide. These are to be formed into slubbings. To effect this they pass between rollers arranged in

the following way.—Two wooden rollers are placed parallel to each other, and in the same horizontal plane, about 6 inches apart; over these is a continuous belt of leather: between these and above them is placed a third roller, covered with leather, which rolls in contact with the leather belt. This upper roller has also an *end-on* motion; it travels constantly about 2 inches forward and back again in the direction of its length. This is done by an eccentric at one end. The strips of wool pass between these rollers, and are thus converted into slubbing; the action being precisely similar to that of the hands when rolling a piece of wool between them, while the revolution of the rollers carries the slubbing forward as it is formed.

The arrangement of the rollers is shown in section in Fig. 2379, having the end on motion. The slubbing thus formed passes on to a horizontal reel or bobbin the whole length of the width of the engine, and round this the slubbing from each ring of card is wound. This when full is removed and placed on the mules in a horizontal position, when the mule draws out from it just as it would from the cops of slubbing. Thus the slubber and piecing children are entirely dispensed with, and the work is done much more regularly.

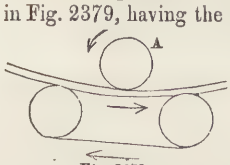


Fig. 2379.

Weaving, &c.—The threads being now ready for weaving into cloth, require to be arranged for the loom. The process of weaving has been fully described under that head, [See WEAVING], but there are a few particulars connected with the preparation of the yarns for the loom which may be briefly noticed. In the operation of warping it is generally necessary to wind the threads into bobbins for the purpose. When this is done, the yarn is first reeled, a number of naps being placed in a line in front of a long reel, which is turned by a handle, and the thread from each nap is wound round the reel, and forms a skein. Each skein is then placed on a smaller separate reel, and the thread wound off upon a bobbin, either by hand or more usually by a simple machine, which winds a large number at once. The operation of winding the thread from the skeins on to the bobbins is termed *spooling*, the bobbin when full of thread being called a *spool*.

In sizing the yarns, the whole chain is sometimes operated on at once, but more usually the skeins are each sized, previous to warping, in a trough filled with a solution of glue, in the proportion of about 1 lb. of glue to 3 gallons of water. The skeins are soaked in this trough, and as each one is taken out it is passed between two rollers, covered with cloth, the upper one of which is pressed upon the lower by weights. In passing between these rollers, the excess of size is squeezed out of the skein, and after hanging in a heated room for a short time, they are ready for spooling. When the whole chain is sized at once, a better method is adopted for drying it: a cylindrical reel, having at each end six arms projecting beyond the reel, at right angles to its axis, is mounted on bearings, and set in motion by wheelwork. The ends of the chain are fastened to the reel, which as it travels round on its axis winds up upon itself the threads of the chain; the projecting arms, which are of iron, are in the form of a sort of trough, the open side of which is turned inwards; and as the reel travels round, a long wooden rod is fitted into a groove between two opposite pairs of arms; another rod is similarly placed between the next two opposite pairs of arms, and so on as each pair comes round, the winding-up being performed slowly in order to give the man time to arrange these bars in their places. The object of this contrivance is, that as the chain is wound up, each turn of threads may be kept separate from the one before it, and the coils of the chain be thus left open so as to allow the air to get between and among the threads. The part of the room in which this apparatus is placed is next shut close up, and the reel or *balloon*, as the apparatus is called, is made to revolve rapidly. Hot steam-pipes are laid on the floor below the balloon, and the heat from these, together with the rapidity of motion, effectually dry the whole chain. In winding the chain on to the balloon from the large balls of thread into which it is formed by the warper, a separater or ravel is fixed in front of the reel and parallel to it; this ravel, as noticed under WEAVING, is like a large comb, consisting of a number of reeds or pieces of wood stuck into a rail of wood; between these teeth the threads of the chain are passed, and this serves to keep them separate, and of the right width of the intended cloth. The chain is next *beamed*, or wound upon the beam of the loom, from off the balloon, the threads being again passed through a ravel to keep them apart. If the chain is sized in skeins the weaver receives it in the form of a large ball of threads, and he beams it on the loom, using a ravel to keep apart the threads, while an assistant turns the beam and winds up the chain.

The number of threads in the chain or warp of a cloth is calculated by *biers*, a *bier* consisting of 40 ends or threads, and there being 5 biers or 200 threads to the hundred.

In ordinary broad-cloth there are about 1,800, or 3,600 threads in the warp; these would be set in a sley or reed on the loom about 12 qrs. 3 nails wide, 2 ends or threads passing between every dent or reed of the sley. The width, when finished, will be 7 qrs.

A *Venetian* would have about 29 hundreds, 3 biers, or 5,880 threads; would be set in sley 7 qrs. 3 nails, with 4 ends in a reed; and would be, when finished, 6 qrs. 2 nails wide (or 56 inches).

A common fancy cloth, known under the general name of Heather, has 16 hundreds, or 3,200 threads, is set in sley 7 qrs. 2 nails, and has 4 ends in a reed. This will be 56 inches finished.[1]

(1) Mr. Sheppard remarks:—"I have given these three as specimens of various kinds of cloth, broad cloth being the regular old-fashioned article known in the trade as *cloth*. The Venetian is a cloth which has a small neat twill on the face: it was our own make originally. The other is from an article which we are now making, and may be taken as a general specimen of that class of goods."

In the production of stout cloths for winter wear, a method was introduced in 1838, by Messrs. Daniell & Wilkins, of weaving a double cloth, so that while one side is coarse and warm, the other side may be of the highest finish. This cloth is soft, pliable, and durable.

Braying, Scouring, &c.—The first operation the cloth undergoes after it is woven is *braying*, the object of which is to get rid of the oil used preparatory to spinning, and of the size used in dressing the warp. The cloth as it leaves the loom is greasy and rough, and it is subjected to a number of processes, which make it compact in texture, and smooth and level in surface. The first of these consists in working the cloth in the *stock*. In this operation the *scouring-stocks* are used—a somewhat rude machine, which, under the name of the *fulling-mill*, is supposed to stand in point of antiquity next to the corn or flour-mill. The fulling-mill consists of two or more ponderous mallets of oak, working in a *stock*, as the frame of the mill is called. The mallets are worked by *tapit*-wheels, acting upon their shanks, raising them to a certain height, and then suddenly releasing them; this allows their heavy heads to fall by their own weight. The cloth is exposed to their action in an inclined trough, the end of which is curved, so that the cloth is turned round and round by the action of the stocks, and every part in turn exposed to the blows. The trough contains some liquid detergent substance. It is more usual, however, to employ a machine called a *washer*, consisting of two large heavy rollers, either of wood or iron, the upper one resting on the lower; between these rollers the cloth passes, and dips down to a trough or bath of water or other liquid beneath the rollers. This form of washer is called a *scouring-machine* in Yorkshire. The detergent substances used in the stocks or in the washer are stale urine and hog's-dung: the action is continued for an hour, then the cloth is run through another washer with urine alone, and then with clean water until the latter runs away clear: a little fullers'-earth is also used in this process, and sometimes a small quantity of sôda. The cloth is then dried by being hung up loosely in the stove—a large room heated by steam-pipes—and after drying, it is *burled*. In this process, a woman, called a *burler*, spreads the cloth over a sloping board in front of her, and passes her hand over the cloth to feel the knots which have been made by the weaver; these she picks off with a small pair of iron tweezers made on purpose, and in this way removes all knots and unevenness.

Milling or *Fulling*.—The cloth has now to be *milled*. This is a very important process in the manufacture of broad cloth, as by it the fibres of the wool are felted together, and the whole surface of the cloth is covered with a thick fulled face. The stocks or fulling-mill consist, as above described, of an iron framework supporting the ends of two or more heavy wooden mallets, which are raised by projecting cams on a wheel which revolves under the nose of the mallets: the wheel raises the heads of the hammers to their full height, and then, releasing them, allows them to fall by their own weight on the cloth, which is contained in a sort of iron trough beneath the mallets. Soap is used in this process. The bars of soap are first converted into shavings by a rough plane, and

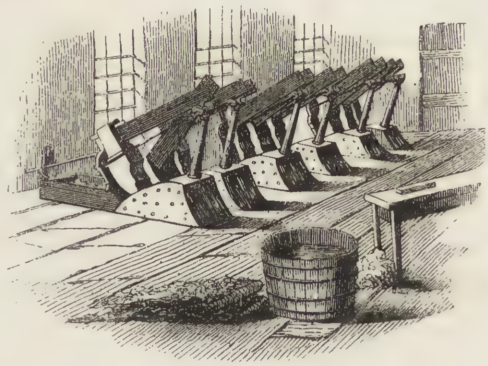


Fig. 2380. FULLING-STOCKS.

these are dissolved in hot water. The soap is distributed over the cloth by pouring it into a fold near one of the ends; the man then takes up this fold, and pulls out the cloth so as to form a sort of channel, along which the solution of soap flows, until the cloth has absorbed it all. The cloth is taken out two or three times during the process of milling to prevent its forming into wrinkles.

An ordinary broad cloth will take from 60 to 65 hours to mill, and will require about 11lbs. of soap; it will shrink during the process from 12 quarters wide to 7, and from 54 yards long to 40. A Venetian will require about 12 hours, take from 6 to 7lbs. of soap, and shrink in width from 7 quarters 3 nails to 6 quarters 2 nails, and in length from 54 yards to 45 yards. A Fancy Heather will require 10 hours, take 10lbs. of soap, and shrink in width from 7 quarters 2 nails to 6 quarters 2 nails, and in length from 54 to 49 yards. After the fulling, the cloth is passed through a washer with clean water, to remove the soap.

A great improvement has of late years been introduced to supersede the old fulling-stocks: a machine called the *Fulling-machine* is now coming into general use; it is more convenient, does the work in a shorter time, and requires less soap. It consists of a strong iron framework, A A, fig. 2382, supporting a wooden case, B B, which is screwed on to it; C C, are strong cog-wheels, the lower one of which is set in motion by the drum K, fig. 2381. On the axis of these wheels are fixed two narrow wooden rollers, which are shown in section in fig. 2383; the lower one, D, has a copper flange on each side, the use of which will be noticed presently. On a horizontal line, passing between these rollers, there is fixed a sort of trough or shoot, F, a part of the top of which is moveable on a hinge, as shown in Fig. 2383: at the end of this movable lid there is a kind of box, H, in which weights are placed. The upper roller E is pressed on the lower one by the springs S, the force with which they press downwards being regulated by the nuts at the ends of the rods attached to the springs. The cloth is shown in fig. 2381, in the position which it occupies while being milled;

the two ends of the cloth are fastened together so as to form an endless cloth. Passing through two holes in the piece of wood O, the two parts of the cloth pass together over and between guide rollers till the united cloths pass between the rollers E D, being kept in place by the copper flange before mentioned. The action of these rollers forces the cloth on into the trough F, where it is doubled and folded up in

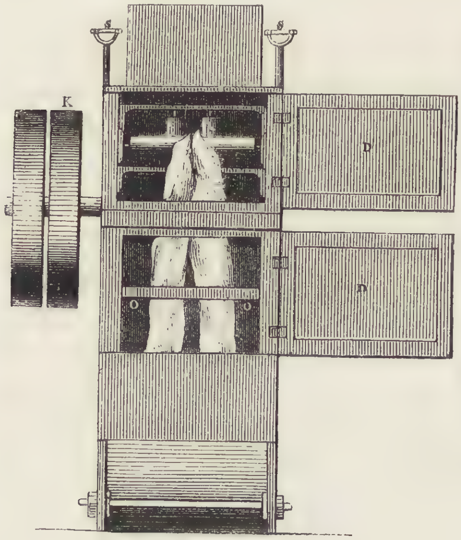


Fig. 2381. FULLING-MACHINE.

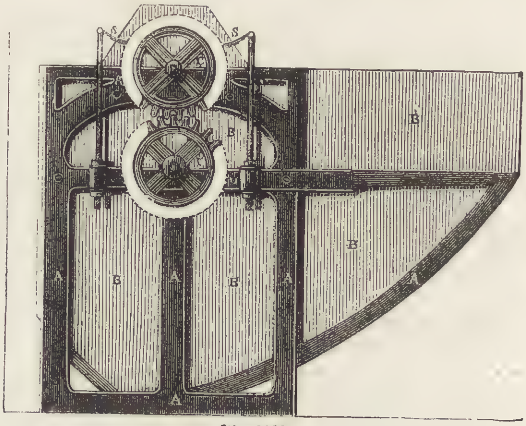


Fig. 2382.

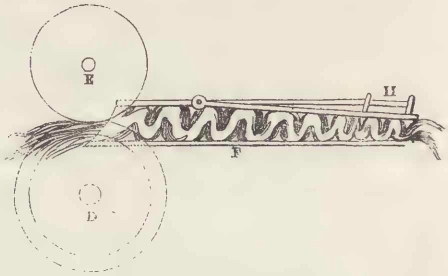


Fig. 2383

the way represented, the weights in the box H preventing it from passing freely out of the trough. The force thus exerted between the rollers and in the trough has the effect of milling the cloth and causing the fibres to felt together, just as in the stocks. Soap is added by being poured on the cloth in front of the machine as it is at work, the doors D D being made to open for that purpose.

Teazling.—After being dried, the cloth has to be *dressed*; this is done at the gig-mill. It is first *roughed* or *rowed*, by being teazled both ways, so as to raise the wool for about 20 hours. The operation of teazl-

Fig. 2384.

ing is performed by means of the prickly flower-heads of the Teazle, Fig. 2384, a species of thistle (*Dipsacus fullonum*), which is cultivated in the clothing counties, for the purpose.[1] From 2,000 to 3,000 teazles are used on a piece of cloth 40 yards long; each head consists of a large number of flowers, separated from each other by long scales, at the end of which is a fine hook, which forms the efficient part of the teazle. These natural hooks are sufficiently strong to overcome slight impediments, but if they become fixed in a knot which they cannot disentagle, they break. It is this property, so difficult to imitate, which has hitherto prevented the introduction of wire brushes or metallic teazle-cards; for their points or hooks, instead of yielding, tear out the fibres, and injure the surface of the cloth.

Cloth was formerly teazled by hand, a number of teazle-heads being fixed in a small wooden frame with cross handles 8 or 10 inches long, with which the surface of the cloth was worked, first in the direction of the warp, and then in that of the weft, the cloth being damped for the purpose; when the teazle-heads had become choked up with wool, they were cleared out by children with small steel combs, and when the teazle-points had become soft by moisture, the heads were set aside to dry.

Teazling is now performed by machinery. In the *Gig-mill*, Fig. 2385, the teazles are arranged in long frames attached to a hollow drum or cylinder, and the

(1) The teazle is a biennial plant, and is sown in drills: it is thinned out by the hoe, and kept clear from weeds during the first year, and also weeded during the second year. The ripe heads are cut and dried for sale. The crop is an uncertain one, and liable to be spoilt by a continuance of wet weather. In Yorkshire the average price of a pack of teazles, containing 13,500 heads, in the proportion of 6 large to 4 small heads, is from 5*l.* to 7*l.*, and in times of scarcity as much as 22*l.*

cloth, guided by a number of rollers, is moved in a direction contrary to that of the cylinder, by the rapid revolution of which, and the slower motion of the cloth in a contrary direction, the loose fibres of the wool are brought to the surface. When the teazles become clogged with wool, they are removed

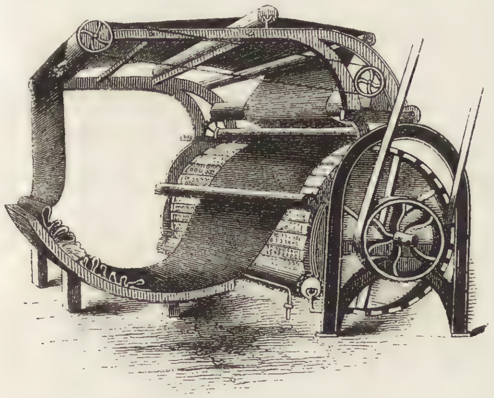


Fig. 2385. GIG-MILL.

from the cylinder and cleaned. In the gig-mill in use in Messrs. Sheppard's mill, the cloth is wound on a roller beneath the large cylinder carrying the teazles, and from this passes over the teazles, and is then wound up on another roller above. Two boys attend to one gig to pull out the cloth, and reverse the motion when it has been rowed once, so as to re-wind it on the lower roller.

Shearing.—The filaments drawn out by teazling are of unequal length, and require to be shorn to make them level. The *shearing* of cloth is an important operation, and is varied according to the quality of the material and the appearance required. It was formerly done by hand with a pair of shears, and the introduction of machinery for the purpose at the beginning of the present century led to serious riots in the West of England. One arrangement for mechanical shearing consists of a fixed semicircular rack, within or behind which is a cutting edge called a *ledger-blade,* and a large revolving wheel containing 8 small cutting-disks, which, in contact with the ledger-blade, form a number of delicate cutting-shears; each cutting-disk is furnished with a tooth-pinion working into the semicircular rack, so that as the large wheel revolves the cutting-disks acquire an independent rotatory motion, in addition to their revolution with the large wheel. In Fig. 2386, the cloth is represented by the shaded parts, and the machine may be made to travel over the cloth, or the cloth may be moved beneath the stationary machine. The machine, however, which is chiefly used for the purpose, is *Lewis's Cutting-machine:* it consists of an iron cylinder (the length of which is equal to the width of the cloth) with cutting-blades passing spirally round it, and a straight steel blade is fixed in contact with these cutter-blades and parallel to the cylinder. Anything placed between this blade and the cutter-blades will, when the cylinder is turned round, be cut as if with a pair of scissors; the whole apparatus is movable on a hinge. The cloth passes over another steel blade directly below the cutter, and thus the wool is exposed to the action of the latter, which, rapidly revolving, shears it off. The depth to which the cutter is allowed to fall on the cloth is regulated by small pieces of paper put under a projecting stud, and the falling out of one of these papers is sufficient to damage the piece of cloth. The whole cutter is supported on a frame, and travels over the cloth across its width; as soon as it has been over once it is drawn back, the cloth is shifted on, and the cutter again travels over it. Two boys generally attend to two cutters, and one man has the superintendence of the shop, and attends to the papers, and regulates the depth to be taken off at each kerf or cut. This is a delicate operation, as the cloth requires to be cut many times. If too much were taken off at once, the surface of the cloth would be injured.

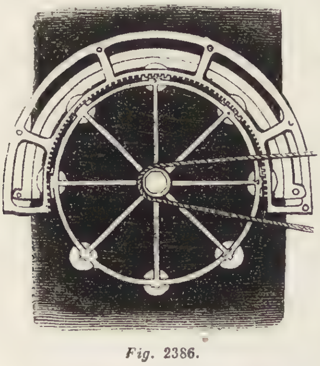


Fig. 2386.

The Broad Perpetual, Fig. 2387, is used for cutting the backs of some goods, or the face of some dry-

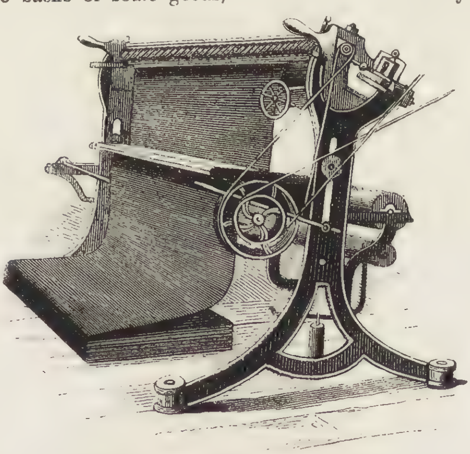


Fig. 2387. CLOTH-SHEARING MACHINE.

dressed articles, such as the heathers mentioned before. It is in extensive use in Yorkshire, but it does not answer well for *blacks* or *fine cloths.*

In shearing fine cloth it is cut, 1*st way,* 5 or 6 kerfs being taken off, a kerf being the wool taken off at one passing through the cutter. It then goes back to the gig-mill, and is *mozed* or teazled one way for 3 hours or so, then dried and re-cut, 2*d way,* 6 kerf or more being taken off.

Pressing.—The next of the finishing processes is to arrange the cloth in regular folds, and submit it to the action of a hydrostatic press. A polished pressing-board is placed between each fold, to prevent the surfaces of the cloth from coming in contact; and the

pieces of cloth, where many are pressed at the same time, are separated by an iron-plate between every two pieces. For hot-pressing, 3 hot iron-plates are inserted between the folds at intervals of about 20 yards, and the heat of the plates is moderated by thin sheets of cold iron placed above and below the hot plates. The pieces of cloth are piled up in the press, and subjected to an intense pressure, which is maintained until the plates become cold. The cloth is then taken out, and folded again in such a way that the creases of former folds may come opposite the flat faces of the pressing-boards and be removed at the second pressure. Hot-pressing gives a satiny lustre and smoothness to the face of the cloth; but as this is apt to become spotted by rain, another process has been introduced, namely, *Boiling*. The cloth is tightly wound upon a wooden or iron roller, and immersed in water, heated to 170° or 180°, for 5 hours; it is then taken out and allowed to cool for 24 hours. It is treated in this way four or five times in succession, and then washed with fuller's-earth. After this it is racked or stretched tightly on an iron frame, called the *rack* or *tenter*, in a stove, or room heated by steam pipes.

In place of the roller-boiling another process is now often adopted, called *Steaming*. After the cloth is hot-pressed, it is rolled round a hollow copper roller, perforated with a number of holes, a piece of cloth being wrapped round the roller first, to protect the cloth from being coloured by the copper: steam is then admitted into the roller, and allowed to pass through all the folds of cloth. If high-pressure steam is used, this will be effected in 5 or 10 minutes; but if the pressure is low, it will require 1½ hours: after this it is boiled twice. This steaming process saves the time of 3 boilings, and gives a nice satiny finish to the goods.

Several of the processes which we have thus described separately, are frequently alternated with each other. The cloth is passed several times through a Brushing-machine, consisting of a series of brushes attached to a cylinder. In passing through this machine the face of the cloth is softened by being slightly damped by exposure to steam, which escapes in minute jets from a copper box, extending the whole length of the brushing-machine.

In finishing the cloth previous to cold-pressing, it is carefully examined before a strong light, and *picked*, *fine-drawn*, and *marked*. Picking is similar to burling, its object being to remove blemishes from the surface, and to cover any spots which may have escaped the action of the dye, by touching them with a pen dipped in dye-stuff. The object of fine-drawing is to close any minute hole or break in the fabric, which is done by introducing, by means of a needle, sound yarns in the place of the defective ones. Marking consists in working in with white or yellow silk a word or mark, indicating the quality and number of the piece. The cloth is lastly made up for the market, in *pieces* or *bales*, and into *ends* or *half-pieces*.

It is stated in the Jury Report, Class XII., that "The continental methods of producing a permanent face are totally different, much shorter in their processes than ours, and performed at a much cheaper rate. Their methods are—the one by rolling the cloth tightly round a hollow perforated cylinder, into which the steam is introduced to produce the desired effect; the other, and more general one, by folding the cloth and putting it under very powerful pressure, then allowing the steam to penetrate the whole bulk. Both these methods cause a hardness, which is observable in all continental productions, and would be more so if applied to stouter fabrics. There are also to be seen on cloths, that have been so treated, marks of the folds, which cannot be effaced by any ordinary means. Several houses in Leeds have tried this plan, but found that the fold-mark and hardness of the fabrics formed obstacles to their sale in the home-market, though not for exportation; consequently it has been adopted to meet the competition abroad.

"Considerable attention has been given to the dyeing of cloth in the different countries, especially the finer fabrics, which are all equally well and permanently dyed. In the middle qualities, some are permanently dyed, and others not; this is the case in all countries, and in the lower qualities (with some few exceptions) they are all of a common dye. This is a circumstance easily accounted for by the cost of the permanent dye being considerably more, and from its detracting slightly from the appearance and feel of the cloth,—facts which, it must be admitted, are great impediments in these competitive times, although there can be no doubt that real and ultimate economy must remain with a permanently dyed article."

Section II.—On the Manufacture of Worsted Yarn.

The preparation of worsted yarn resembles that of cotton, and is essentially different from that of *short wool* or *clothing yarn;* for while, in the latter, the fibres are entangled and crossed in every direction, in order to assist the felting property, care is taken in the preparation of the former to dispose all the fibres as nearly as possible in parallel lines.

The first operation in the preparation of long wool is *washing* in soap and water. Much of the moisture is pressed out by rollers, after which the wool is conveyed in large baskets to the drying-room, where it is spread over the floor. The drying-room is usually situated immediately over the boiler of the steam-engine, and is thus economically heated. When the wool is dry, it is removed to a kind of willowing machine, called the *plucker*. This is attended by a boy, whose business it is to spread the wool, with tolerable regularity, over a feeding-apron, which, by advancing, delivers the tufts of wool to a pair of fluted rollers, which convey it to a fanning apparatus.

After the wool has passed through this machine, it is ready for combing. For the finer descriptions of long wool, this is still done by hand. It is a laborious and unhealthy occupation, being carried on in hot rooms. The wool-comber employs three implements, namely, a pair of *combs*, one of which is represented

in Fig. 2388, a *post*, Fig. 2389, to which one of the combs can be fixed, and a small stove, Fig. 2390, called a *comb-pot*, for heating the teeth of the combs.


Fig. 2388

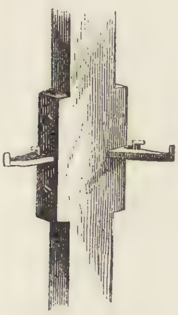


Fig. 2389

The wool-comb is composed of two or three rows of pointed, tapering steel teeth, the rows being of different lengths. They are fixed to a wooden stock or head, which is covered with horn, and from this head proceeds a perforated handle, made to fit into certain projections in the post, upon which the combs are occasionally rested during the operation. The turned-up part of the iron stem enters a hole in the handle of the comb, while the staple near the post enters the hollow end of the handle, thus holding the comb securely.

The comb-pot consists of a flat iron plate, heated by fire or steam; and above this is a similar plate, with sufficient space between the two to admit the teeth of the comb.

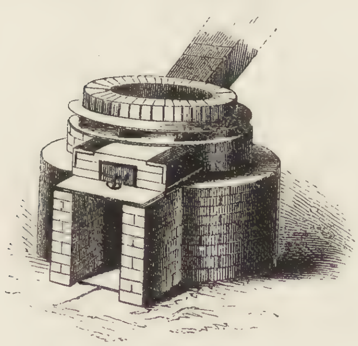


Fig. 2390.

The heated comb being fastened to the post with the teeth upwards, the workman takes a handful of wool, sprinkles it over with oil, rolls it up in his hands to distribute the oil uniformly, and then throws about one-half of the wool over the points of the comb, drawing it through them repeatedly, leaving each time a few straight filaments in the comb. When the handful of oiled wool is thus disposed on the comb, the comb is removed to the stove, so as to expose the wool to the influence of the heat. An empty comb is at the same time taken from the stove and mounted on the post, where it is filled with wool as before. The man then takes the two combs, and, sitting down upon a low stool, holds one of them with his left hand over his knee, and, holding the other in his right hand, introduces the teeth of one comb into the wool stuck in the other, and draws them through it; by which operation the wool is transferred to one comb. This process is continually repeated, until the fibres are laid truly parallel. The man begins by combing out the ends of the wool, advancing gradually from one end to the other, until at length the teeth of the combs are very near together. About one-eighth of the wool remains on the teeth of the comb after each operation; and this quantity, which is called *noyl*, being too short for the comber to grasp in his hand, is transferred to the short-wool manufacturer. The wool, after it has left the comb, requires to be combed again, at a lower temperature, before it is fit for the spinner.

Many attempts have been made to supersede this operation by self-acting machines. One of these consists of 2 large wheels, 10 feet in diameter, set nearly upright, the comb-teeth forming a circle round the rim of each wheel, at right angles to its plane, the points of the comb in the 2 wheels being turned towards each other. The wheels are furnished with hollow iron spokes, filled with steam, for the purpose of maintaining a proper combing heat. A boy, seated on the ground, strikes the wool in handfuls upon one wheel, which is made to revolve slowly for the purpose. The wheel is then made to revolve more rapidly, and the teeth of one wheel, sweeping obliquely over the teeth of the other, smooth out the tangled locks with great delicacy and precision. "When the wheels are set in rapid motion, the loose ends of the fleece, by the centrifugal force, are thrown out in the direction of radii, upon the teeth of the other revolving comb-wheel, so as to be drawn out and made truly straight. The operation commences upon the tips of the tresses, where the wheels, by the oblique posture of their shafts, are at the greatest distance apart; but as the planes slowly approach to parallelism, the teeth enter more deeply into the wool, till they progressively comb the whole length of its fibres. The machines being then thrown out of gear, the teeth are stripped of the tresses by the hand of the attendant; the *noyls*, or short refuse wool, being also removed, and kept by itself."

Breaking, Drawing, and Spinning.—The wool, as it is combed into slivers, is formed into narrow bundles, called *tops*, each containing about a pound and a half or two pounds. These being unrolled, the slivers are separated and thrown loosely over a pin, within reach of the attendant, who takes a sliver, spreads it flat upon an endless felt or feeding-board, presenting the end to the first pair of rollers of the *sliver-box* or *breaking-frame*, which draw the sliver in. When it has passed half through, the end of another sliver is placed upon the middle of the first, and they are drawn through together. Care is taken to splice the long end of one sliver to the short end of another. When this second sliver has passed half way through, the end of a third is placed on the middle of it; and in this way the short slivers are united and extended by other pairs of rollers into one long and uniform sliver, 8 times the length which it had on the feeding-board. The slivers from this machine are received into cans, the contents of 8 of which are drawn into one at the drawing-frame. These are also received

into cans, and being again drawn out and slightly twisted, are wound upon bobbins. At about the fifth drawing, a number of yards are weighed, so as to ensure a given length to a given weight of yarn. If the sliver is not of the length required for the size of the worsted intended to be spun, the speed of the drawing-frames is changed accordingly. The roving and spinning so closely resemble those processes in the cotton manufacture as to require no further description in this place.

Section III.—Statistics.

The woollen and worsted manufactures have undergone several changes, consequent on the introduction of improved machinery and steam-power. The seats of the manufacture were originally determined by the facilities for procuring the raw material, and the presence of water-power. Improved systems of conveyance have also had an effect in shifting the localities of the manufacture. Previous to the reign of George III., when the roads of Great Britain were little better than bridle-paths, wool was conveyed on horses, and so general was this employment that the term *pack-horses* had its origin in the packs of wool which they carried. Under such a slow and expensive system of conveyance the manufacturer would be induced to settle in districts where the wool was grown, and where a market existed for the disposal of his manufactured products. The quality of the wool produced in the neighbourhood would also greatly determine that of the cloth. Such circumstances as the above led to the establishment of a large number of small manufacturers in different parts of the country, each master giving employment to his poorer neighbours and their families, who had their spinning-wheels and looms in their cottages, and a number of children and servants worked under the direction of the master himself. But when turnpike roads were adopted, and canals came into use, the woollen manufacturers gradually established themselves in South Lancashire and the West Riding of Yorkshire, where, by means of canals, a cheap and easy means of communication was opened to Liverpool and to Hull; which sea-ports now began to receive wool from various parts of the kingdom, and indeed of the world, thus opening markets both domestic and foreign for the disposal of the manufactured goods. The natural capabilities of Lancashire and Yorkshire—such as its water-falls, its coal, iron, and limestone —furnished great facilities for the construction of machinery; accordingly in these counties the manufacture of coarse woollen goods continued for many years to flourish. Gloucestershire, Wiltshire, and Somersetshire producing the finest English wools, long maintained their reputation for fine cloth; and those counties, moreover, had the advantage of Bristol as a sea-port, which supplied them with the fine wools of Spain and Portugal. The finest cloths of the West of England were sent to the Blackwell-hall factors in London, for sale and distribution. The introduction of the merino sheep into the north of Europe, as noticed in an early part of this article, led to the production of wools superior even to those of Spain—a circumstance which, coupled with the increasing facilities of communication, enabled the Yorkshire manufacturers to obtain supplies of fine wool, and thus to rival the West of England in the production of fine cloth.

The Yorkshire clothing district extends from north to south about 40 miles; its mean breadth is about 20 miles; so that it occupies an area of about 800 square miles: it includes the large manufacturing towns of Leeds, Huddersfield, Bradford, Halifax, and Wakefield. Leeds is now regarded as the first town in England for the extent and variety of its manufactures in wool; its chief trade is in the middle and lower qualities. This town and the surrounding district contributed to the Great Exhibition an extensive assortment of woollen cloths in fine, middle, and low qualities, cloakings, beavers, mohairs, doeskins, cassemiere, cashmerettes, tweeds, and pilots, which, for appearance and cheapness, according to the verdict of the Jury Report, Class XII., maintained the high position for which it has so long been in repute. The manufacturers of Leeds largely supply the foreign markets, and vary their productions according to the taste and requirements of each. Huddersfield and its neighbourhood rank next to Leeds in importance, and supply a great quantity and variety of goods. "Here an immense portion of the fancy trowserings are made, beside broad-cloths; but the productions of Huddersfield are principally for home consumption, and of the middle and lower qualities. This town, in 1820, made goods from home-grown wool only, but since that period it has risen into great importance." In the Exhibition a number of double-faced cloths from this seat of manufacture attracted much notice. They presented a different colour on each side, an idea probably suggested by Daniell's double cloth already referred to. At present these coloured cloths must be considered rather as curiosities than as a legitimate branch of manufacture. Most of the *cloth* produced in this district is from the neighbourhood of Leeds, Wakefield, Huddersfield, and Saddleworth; Leeds being the great mart for coloured or *mixed* cloths, as they are called, which are wholly made of dyed wool, and *white* broad cloths. *Flannels* and *baizes* are manufactured in and near Halifax, and also cloth used for the army. The *blanket* and *flushing* trade is carried on in the district between Leeds and Huddersfield. *Worsted*-spinning is extensively carried on at Bradford, and *stuffs* are made in its vicinity, and also at Halifax and Leeds. *Narrow cloths* are made in and near Huddersfield. Broad cloths and kerseymeres are made at Saddleworth. Wakefield was long celebrated for the skill of its cloth dyers. Dewsbury is the chief seat of what is called the *shoddy trade*. Old woollen cloth, &c., which was formerly used as manure, and cast off woollen clothing of every kind, now form the staple of this trade. The materials are subjected to certain preparatory processes, after which they are torn to pieces by machinery, and reduced to the original condition of wool, which is spun again, sometimes with an admixture

of fresh wool, and is again woven into cloth. Shoddy cloth answers very well for the purposes of padding, &c., and was long confined to such uses; but the improvements effected in its manufacture, and especially in the art of dyeing it, have led to its application to blankets, flushings, druggets, carpets, table-covers, cloth for pilot and petersham great-coats, &c. It is even used largely in making the clothes of the army and navy; and most persons, at some time or other, wear clothes (especially if they are cheap) made of shoddy cloth. Woollen table-covers are commonly made of shoddy, the pattern being printed by means of aquafortis. Rochdale, in Lancashire, manufactures flannels, baizes, kerseys, and broad-cloths.

In the West of England, Gloucestershire still maintains its trade, Stroud and its neighbourhood being the chief seat of the manufacture. Stroud, or Stroudwater, is so called on account of the purity of its waters, which have been celebrated for centuries for dyeing scarlets and other light colours. Fine broad cloths are manufactured in this neighbourhood, and also at Ebley, Eastington, Stonehouse, and Minchinhampton. Trowbridge, in Wiltshire, is the next town and neighbourhood of importance in the West: it manufactures largely and well. Bradford, Wilts, is less noted than formerly. Chippenham, in Wiltshire, makes some first-rate superfine broads; and Melksham, in the same county, is also in some repute. Frome, in Somersetshire, is not so much celebrated as formerly for superfine *broads*, but it has a high character for fancy *six-quarters*. At the Great Exhibition were some beautiful specimens of cloths, beaver, and Venetians, from Frome, and from Twerton, near Bath. Scotland makes some excellent goods of a cheap description for trouserings.

Halls, for the sale of cloth, are established at Leeds, Halifax, Huddersfield, Bradford, and other places. The following notice of the Coloured-cloth Hall at Leeds, was prepared from personal inspection by the Editor for his work on "The Useful Arts and Manufactures of Great Britain," and will probably be a sufficient description of the management of these buildings. There are two cloth-halls at Leeds: the Coloured-cloth Hall, built in 1758, and the White-cloth Hall, built in 1775. The cloth-market was formerly held in an open street. The Coloured-cloth Hall is a plain building, occupying three sides of a large square, divided into 8 compartments, which are called streets: these are, King-street, Queen-street, 'Change-alley, Mary's-lane, Prince of Wales's-street, Cheapside, Commercial-street, Union-street, and New-street. Each street contains two rows of stands facing each other: each stand projects from the wall 11 or 12 feet; but it measures only 22 inches in front: it is inscribed with the name of the clothier to whom it belongs. No one can occupy a stand unless he has served a regular apprenticeship to the clothing business. Each stand, which is the absolute freehold property of the holder, cost originally about 3*l.*; and the value has been as much as eight or ten times that amount; but, since the extension of the factory system, a good deal of cloth produced in the woollen district is sold without passing through the halls, which have, consequently, lost much of their importance, and the stands do not now exceed their original value. The markets for the sale of coloured cloths are held on Tuesdays and Saturdays, on which days only are the merchants permitted to make their purchases in the halls. The time of sale commences, by the ringing of a bell, at nine o'clock in summer, and half-an-hour later in the winter half of the year from October to March. At the end of an hour the bell is rung again, to warn the buyers and sellers that the market is about to close; and in another twenty minutes the bell is rung for the third time; after which, a fine of 5*s.* is imposed on every buyer. The White-cloth Hall, situated in another part of the city, is opened immediately afterwards, and is subject to similar regulations. The cloth is brought to the halls in the undressed state; the purchasers, who are the proprietors of what are called *finishing-shops*, conduct the various finishing processes described in SECTION II. The goods produced in the West of England, and in Norfolk, are not sold in cloth-halls, but at public fairs or markets, or to the agents sent round by the drapers.

In this notice of the woollen and worsted manufacture, it might be expected that some details should be given of the modes of manufacture of the various descriptions of goods in which wool is employed; but it may be stated that such goods as blankets, flannels, baize, stuffs, merinos, mousseline-de-laines or wool muslins, bombazets, tammies, shalloons, says, moreens, calimancoes, camlets, lustrings, and a number of others, are produced by some of the means already described under WEAVING. Many divisions and subdivisions of the manufacture differ more in their results than in the means by which those results are attained. The mixture of woollen with worsted yarns, or either of them with cotton or silk, together with various methods of dyeing and fancy weaving, leads to an almost endless variety of woven fabrics. Thus, to give a few examples :—*kerseymere* is a fulled twilled fabric; *serges* are also twilled, but the warp is worsted and the weft woollen; *blankets*, and many varieties of plain coarse cloth, are made of very soft yarn, afterwards worked up into a kind of pile by milling; *bombazeen* is a mixture of worsted and silk, twilled; *poplin* is a similar mixture produced by plain weaving; *stuff* is entirely worsted; *merino* is a fine woollen twill; *saxonies* and *orleans* are made of woollen mixed with cotton yarn: *cashmere* ought properly to be made of the wool of the Cashmere goat; but most of the fabrics named *cashmeres* are made of sheep's wool; *challis* is produced from a silk warp and a woollen weft, and is usually printed; *mousseline de laine* was, as its name implies, originally all wool; but it is now commonly mixed with cotton, and printed; *Norwich-crape* is composed of wool and silk; *Crêpe-de-Lyon*, of worsted and silk. The fabrics called *waistcoatings* are exceedingly numerous.

The condition of the worsted trade at the time of the Great Exhibition may be estimated by the follow-

ing statement from the Jury Report, Class XII.:—"The classification of worsted stuffs contained in the list drawn up for the Jurors has reference to the materials of which they are composed; viz.—

1.	Fabrics composed entirely of wool.	
2.	Ditto	of wool and cotton.
3.	Ditto	of wool and silk.
4.	Ditto	of wool, silk, and cotton.
5.	Ditto	of alpaca and mohair mixed with cotton or silk.

"The first of these divisions comprises the well-known fabrics called 'merinos' double-twilled, so denominated from the Spanish wool of which they were first manufactured. In this article the French have always had an unquestionable superiority, and many of the specimens in the Exhibition fully maintain their reputation. There are some goods of this class, however, in the Bradford department, but little inferior to them. In single-twilled merinos the worsted manufacturers of Yorkshire have at all times had the decided preeminence. Shalloons, says, serges, lastings—all stout and heavy articles—are manufactured chiefly at Halifax and at Keighley. Damasks for curtains and hangings are also made at Halifax, and this branch of the trade has arrived at great perfection, both in excellence of material and elegance of design. Of the fabrics composed of wool and cotton, the articles denominated Cobourg and Orleans cloth—the former being twilled and the latter plain—have been staple manufactures, of which the consumption has been immense; they are made chiefly at Bradford and Keighley. Many of the silk warp and worsted weft fabrics are distinguished by their richness and durability. The alpaca and mohair manufacturers (carried on at Bradford and Bingley) are remarkable for their softness and brilliancy, and the great variety of purposes to which they are applicable. The importation of alpaca wool has increased from 7,000 bales in 1836 to 20,000 bales in 1850, and of mohair, from 5,621 bales in 1841, to 12,884 bales in 1850. It is in the production of articles in which wool of various kinds is combined with cotton and silk, that the superiority of the British manufacturer is most apparent, no such goods being produced on the Continent in any extent, or of any great excellence. This result could not have been attained, had not the skill and enterprise of the manufacturer been aided by that of the worsted dyer. The chemical processes required in order that a fabric composed of both vegetable and animal substances may be made to receive an equal and regular dye are necessarily varied and intricate; but so successful have been the efforts of the dyers, that goods made of white cotton warp and worsted weft can be dyed quite as perfect in colour as French merinos composed of wool alone.

"The consumption of these various manufactures is immense. The looms are capable of producing upwards of 80,000 pieces per week, averaging 30 yards each. These goods are not only sold in the United Kingdom, but are largely exported (as the following returns will show) to the United States of America, and to Germany, and other parts of the Continent of Europe.

"Exports, during the six months from the 1st of January to 28th June, 1851:—

Woollen and worsted yarns	5,567,854 lbs.
Woollens and cottons, mixed (value)	830,478*l.*
Stuffs, woollen and worsted ditto	1,896,228*l.*

"All that is now wanting in the English worsted trade is, that the same enterprise should be exhibited as heretofore in the working up of materials into new forms, combined with greater taste in the production of fancy goods."

Some further statistics respecting wool will be found under WEAVING, SECTION VIII.

WOOTZ, or INDIAN STEEL. When highly carburetted steel is fused with alumina, a white, granular, brittle alloy is formed, containing 6·4 per cent. of alumina. On fusing 67 parts of this alloy with 500 of steel, a compound similar to Bombay Wootz is obtained. Polished surfaces of this material, when washed over with dilute sulphuric acid, show the *damask* of the celebrated sabres of Damascus, which renders it probable that they were formed of this substance. The process of Damasceening is described under GUN. See also INTRODUCTORY ESSAY, page cxv.

WORSTED. See WOOL.

WORT. See BEER.

WOULFE'S APPARATUS. See DISTILLATION, Fig. 717.

XANTHINE. See MADDER.

YARD. See WEIGHTS AND MEASURES.

YARN. See COTTON—FLAX—WOOL—WEAVING.

YEAST. See BEER.

YEW. See WOOD.

YTTRIUM (Y 32). The metal of a very rare earth discovered by Professor Gadolin, in 1794, in a mineral from the quarry of Ytterby in Sweden. The mineral, which has been called *Gadolinite,* is composed of yttria, silica, and the oxides of iron and cerium. Several processes have been described for obtaining yttria (YO); but it is probable that the substance described as pure yttria is a mixture of that oxide with two others, the bases of which have been termed *erbium* and *terbium,* both derived from the word ytterby. These three rare metals have received no application in the arts.

ZAFFRE. See COBALT.

ZERO. See THERMOMETER.

ZINC. (ZN 32.) The ores of zinc were made use of from the earliest times for combining with copper in the manufacture of brass. Zinc is first mentioned as a distinct metal by Paracelsus, but it appears to have been known in China and in India from an early period, articles for use and ornament having been made of the metal. The ores of zinc chiefly used in commerce are the carbonates and silicates, and sometimes the oxide, and the native sulphuret or *blende* The ores occur in veins traversing primitive or transition rocks, or in floors and stockworks in more recent formations. *Red oxide of zinc* is sometimes met with in the crystalline form, as at Sparta, in New Jersey. Its specific gravity varies from 5·4 to 5·5; its lustre is adamantine, and when scratched it gives

an orange-yellow streak. Its colour is red of various hues, in some cases inclining to yellow; it has two distinct cleavages at an angle of 120°; it is brittle, and its fracture is conchoidal. There was a splendid specimen of this mineral in the Great Exhibition, as noticed in the INTRODUCTORY ESSAY, page xcvii. The sulphuret of zinc, or blende, occurs massive, or in dodecahedrons, octohedrons, and other allied forms. When scratched it yields a streak varying from white to reddish brown; its colour varies from resin yellow to dark brown or black, and some specimens have a green or red tint; it has a waxy or resinous lustre, and its recent fracture exhibits a brilliant surface. Its specific gravity varies from 4·0 to 4·1. It sometimes becomes electric by friction. The dark specimens frequently contain sulphuret of iron, and the red specimens a small proportion of sulphuret of cadmium. The dark colour of the former obtains for it the name of *black jack* among our English miners. Blende occurs in rocks of all ages, and is usually associated with the ores of lead, and sometimes with those of copper, tin, and silver. This ore is difficult to smelt, and is therefore not much used as a source of the metal. *Carbonate of zinc*, or *calamine*, occurs in masses of crystals, and in pseudo-morphic forms; its colour is yellowish-white, but if it contain iron, brown or reddish-brown. It has a vitreous, somewhat pearly lustre, white streak, and a cleavage parallel to the faces of the rhombohedron, which is its primitive form. Its specific gravity varies from 4·3 to 4·45. It is one of the most important of the ores of zinc. The *silicate of zinc* or electric calamine occurs in stalactic, mamellated, massive, and other forms, and also crystallized. Its colour is commonly white, but specimens of a blue, green, yellow, and brown colours, are sometimes met with. It has a vitreous lustre and a white streak. Its specific gravity varies from 3·3 to 3·6; its fracture is uneven; its crystals sometimes become electric by heat or by friction; it is a valuable ore, and is found, associated with the carbonate, in various parts of the world.

From the low temperature at which zinc fuses, the reduction of calamine is easy. The ore is first calcined, and is thus rendered friable, and a portion of water and carbonic acid expelled. The roasted ore is reduced to powder under heavy edge-runners, and mixed with a certain proportion of charcoal or coal-dust, and heated in earthen retorts; the carbon combines with the oxygen of the oxide of zinc, carbonic acid is evolved, and the metallic zinc is condensed in receivers. In the neighbourhood of Bristol and Birmingham, the zinc works are supplied with ores from the Mendip hills and from Flintshire, and the works near Sheffield from the mines of Alston Moor. The calamine is freed from galena by hand-picking, and when blende is employed, it is broken into pieces of about the size of a filbert, and roasted in reverberatory furnaces, heated with coal. The roasting is continued ten or twelve hours, during which the ore is kept stirred with iron rakes. The ore loses about 20 per cent. in weight, by calcination.

The furnace used for the reduction of the roasted ore is shown in sectional elevation, Fig. 2391, and also in plan, Fig. 2392, which is taken above the

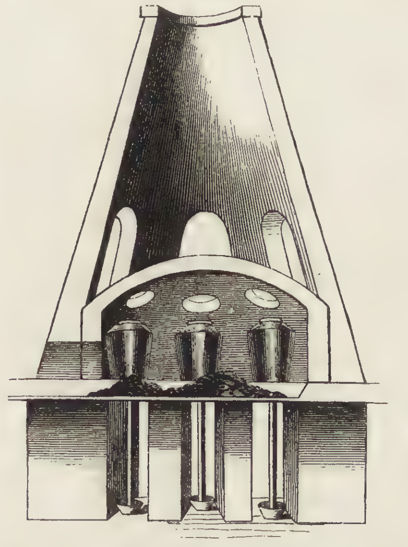


Fig. 2391. ZINC SMELTING-FURNACE. (*English.*)

grate, and in plan, Fig. 2393, taken below the grate. The furnace is similar to that used in glass-houses. Its fire-

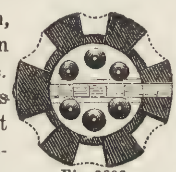


Fig. 2392.

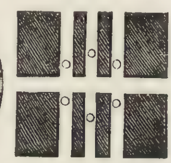


Fig. 2393.

place is raised above the ground, the grate being in the centre, as shown in Fig. 2392; around it are 6 pots for containing the mixture of ore and coal. The pots and the fire are covered in with a dome, furnished, however, with an opening over each pot, for the convenience of introducing the charge; and the dome is surrounded by a conical hood or chimney, containing arched openings for the convenience of the workmen. From the bottom of each crucible proceeds an iron tube, down which the condensed metal passes into a vessel in which the lower end of the tube terminates. The upper end of the tube is closed with a wooden plug, previous to the introduction of the charge; which plug, becoming converted into charcoal by the heat, is sufficiently porous to allow the vapour of the metal to pass down, but does not allow a passage to the coal or calcined metal. Each crucible is covered by a tile, firmly secured to it by means of fire-clay; and as the distillation, *per descensum* as it is called, proceeds, the tubes are prevented from becoming choked with condensed metal, by passing a long iron rod up them from time to time. The zinc is collected in the lower vessel in the form of drops, and the fine powder mingled with oxide, and the whole is fused in a large iron pot; the dross which is skimmed from the surface is mixed with the charge for the next operation; while the metallic zinc is cast into rectangular ingots, and is ready for sale. A furnace of this kind will admit of five distillations in 14 days, during which

from 8 to 10 tons of roasted ore are operated on, and from 20 to 25 tons of coal consumed. The metal obtained varies from 35 to 40 per cent. of the ore treated; and each crucible lasts about 4 months. The crucibles are prepared, annealed, and set, much in the same way as glass-pots. After each operation, the condensing-pipe is taken out, and the residue removed through the hole at the bottom, the piece of charcoal being first broken up with a rake.

Zinc is prepared in large quantities in Belgium and Silesia,[1] and is largely imported into this country. Indeed, it may be said that the Prussian province of Silesia and the kingdom of Belgium, together, possess almost a monopoly of zinc for Europe; the total effect of the whole quantity produced in England, France, and Germany, having but little influence on the commerce in this metal, the manufacture in Silesia, as in Belgium, being greatly favoured by the abundance of the coal.[2]

The smelting of zinc at the Vielle-Montagne, near Liege, differs from the English process. The ore is a mixture of silicate and of carbonate of zinc, both compact crystallized. The gangue, which is of clay, occurs in cavities in the calamine. The ore is exposed to the air for some months, when the clay, being softened by the rain, is readily removed; or, if the ore be very impure, it is washed in a stream of water, by which the clay is readily removed. Two kinds of ore are distinguished, viz. the white and the red; the red contains more iron than the white, but a smaller proportion of zinc. The following is the composition of these two ores:—

		White ore.	Red ore.
Oxide of zinc	zinc	46·6	83·6
	oxygen	11·7	8·4
Silica and clay		14·0	20·0
Water and carbonic acid		22·7	20·0
Sesquioxide of iron		5·0	18·0
		100·0	100·0

The mineral, having been washed, is calcined in kilns, similar to some of those employed in the burning of lime [see MORTARS and CEMENTS, Fig. 1475]. These kilns are heated by two fires at the side, ordinary pit-coal being the fuel; they are covered by an arch, and from them proceeds a flue, which opens into the kiln by 20 openings, *o o*, Fig. 2394, arranged in 4 or 5 rows, each opening being about 4 inches square, and

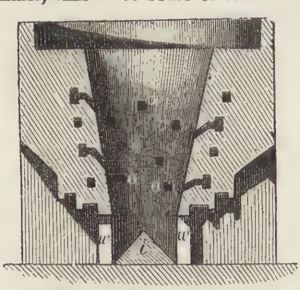


Fig. 2394. ZINC ROASTING-KILN.

lined with fire-brick. Near the bottom of the kiln are 2 openings *w w'* for withdrawing the charge, which is assisted in its descent by two slabs of cast-iron *i*, inclined at an angle of 45°. The charge is put in at the top, and the process is continuous; the kiln being what is called in lime-burning a *running kiln:* the large and the small lumps of ore are mixed together so as to allow the flame and hot air to ascend. In this roasting, the mineral loses its water and carbonic acid, the loss being about 25 per cent. The roasted ore is reduced to powder under edge-runners, similar to those represented under CHICORY, Fig. 566; it is then sifted, and is ready for the reducing furnace. This consists of four distinct furnaces united in one, each in the form of an arched recess, as at F, Fig 2395, the crown of the arch being 8 feet 8 inches above the ground. At the back of this opening is a brick wall *w w'*, inclined as in the figure, the front part *f f'* being left open for the insertion of the retorts *r r*. Below the level of the ground at G is the fire, the smoke and hot air from which enter the furnace by means of 4 openings. Two flues proceed from the arch to a central chimney C, which consists of 4 divisions, each of which is furnished with a damper *d*. The retorts are made of refractory clay; they are cylindrical in form, but closed at one end, each being 3 feet 8 inches long, and 6 inches in internal diameter. Each furnace contains 42 retorts *r r*, Fig. 2395: a retort is also shown separately at *r*, Fig. 2396, together with

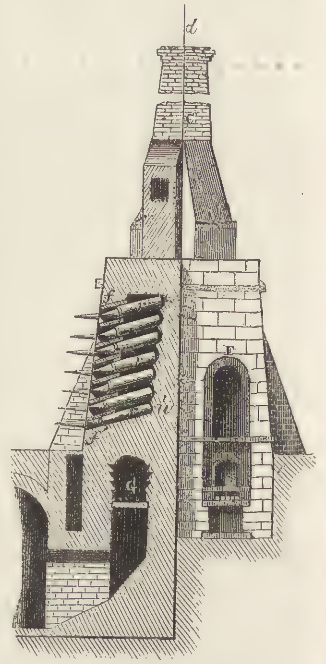


Fig. 2395. ZINC SMELTING-FURNACE. (*Belgian.*)

Fig. 2396.

an adapter *a*, which fits into its open mouth, the adapter being of cast-iron, conical in form, and 16 inches in length, and to this is fitted a cone of wrought-iron *m*, which is about an inch in diameter at the smaller end. There are 8 rows of retorts in each furnace, the wall being arranged in steps, as shown in Fig. 2395, for supporting them; the open ends of the retorts to which the adapters are attached being supported by 8 plates of cast-iron, fixed in the masonry, each plate being a little lower than its corresponding step in the brickwork, so as to allow the

(1) The *Annales des Mines* contain some elaborate notices of the smelting of zinc in Belgium and Silesia. An excellent account is also given in Regnault's *Cours de Chimie*, tome 3e, and also in Phillips's *Manual of Metallurgy*.

(2) The quantity of zinc imported into the United Kingdom in the year ending 5th January, 1853, was, zinc or spelter, 18,505 tons 6 cwt. 3 qrs. 25 lbs.; of oxide of zinc, 787 tons 19 cwt. 2 qrs. 2 lbs.: and there were exported, of British zinc, 1,304 tons 12 cwt.; of Foreign zinc, 5,947 tons 13 cwt. The import is free of duty.

retort to slope with its mouth a little downwards. The spaces between the retorts in front are filled up with fire-clay, and the iron adapters are also made tight with the same material. The charge of each furnace amounts to 1100 lbs. of powdered calcined calamine and 550 lbs. of bituminous coal in fine powder. The coal is slightly washed in water, and well mixed with the calamine. The retorts and the adapters are well cleaned out by means of an iron scraper, and are then charged, the lower retorts being attended to first. The charge is introduced by means of a shovel in the form of a half cylinder, as shown in Fig. 2397; and when all the retorts are charged,

Fig. 2397.

the damper at the top of the chimney is raised, and fresh fuel added to the fire. Carbonic oxide gas is soon evolved in large quantities, and burns with its characteristic blue flame at the mouths of the adapters. After some time, the flame increases in brilliancy; it assumes a greenish white tint, and throws off copious white fumes. This is a sign that the distillation of the metal has commenced, and the wrought iron conical tube is luted on. The fire should now be steadily maintained so as to keep all the retorts as nearly as possible at one temperature; the top rows, however, are usually less heated than the lower ones, and are hence charged with an ore which is easy of reduction—such as the red ore—the white and more refractory ore being contained in the lower retorts. In about two hours the workman removes the cast-iron adapter with a pair of tongs, and strikes it sharply over a vessel which contains the oxide of zinc or *cadmie*, as it is called: the oxide thus detached is added to a subsequent charge. An assistant now holds a large iron ladle under the beak of each retort, while the foreman draws out into it with an iron scraper the distilled zinc which has accumulated at the shoulder formed by the junction of the clay retort and the cast-iron tube: he also separates the metal which has condensed in drops on the interior of the iron cone. The zinc in the ladle is covered by a scum of oxide, which is removed, and the liquid metal is poured into moulds, which form it into flat rectangular ingots of from 75 lbs. to 85 lbs. each. The sheet-iron cone is again luted on, and the heat being maintained for another two hours, another portion of liquid zinc is obtained. In this way the operation is conducted from 6 o'clock A.M. to 5 P.M., the retorts being tapped every two hours. The retorts are then cleaned out and prepared for a second charge, which is worked during the night; so that in 24 hours the two charges yield about 620 lbs. metallic zinc, and from 30 lbs. to 45 lbs. of granulated zinc, more or less in an oxidized state. By this process the calamine yields about 30 per cent. of metal, the residue containing about 10 per cent. in the form of silicate of the oxide of zinc.

When a furnace of this kind is first constructed or recently repaired, the open face of the cavity, Fig. 2395, is closed with bricks or broken retorts, and the temperature is slowly raised to a white heat. After about four days the arched recess is gradually opened, and the retorts, previously annealed at a red heat in a separate furnace, are arranged in their places: they receive at first a small charge of powdered ore and coal, which is increased until the apparatus is in proper working order.

The large demand for zinc-sheeting causes it to be extensively manufactured at these works. For this purpose the zinc ingots are melted in a reverberatory furnace, which has an elliptical half inclined a little towards one side, and at the lowest point is a hemispherical reservoir for collecting the fused metal: the ingots are introduced through one of the doors, and piled on the highest part of the hearth near the fire-bridge. The fused metal is dipped out of the reservoir with iron ladles, and poured into moulds which give it the form most convenient for rolling. The plates thus produced are heated in a second furnace adjoining the first, the heat being supplied merely by the waste gases of the first, by which they acquire a temperature of about 212°, and can thus be rolled into sheets at the ordinary rolling-mill. It is this method of rolling which has caused zinc to be so extensively employed during the last thirty years, previous to which the difficulty of forming it into sheets prevented its application to numerous purposes. The Vielle-Montagne Company have greatly improved the manufacture, as was proved by the specimens contributed by them to the Great Exhibition—such as zinc in very flexible and thin sheets, zinc stamped for a variety of uses, mouldings produced by drawing, nails and spikes of various kinds and sizes, wire of great flexibility, and of all numbers. This company has also employed zinc for castings of large size, the statue of Her Majesty Queen Victoria in the Great Exhibition, with its pedestal, also of zinc, presenting a total height of 21 feet. [See INTRODUCTORY ESSAY, page xcvii.] At the time of the Exhibition this Company had 80 reducing furnaces at work, employing 2,640 workmen, having produced 11,500 tons of zinc in the previous year 1850. The company have also two establishments for the manufacture of oxide of zinc, intended to replace the white and grey lead in house-painting—one at *Asnières*, near Paris, and the other at *Valentin-Coq*, near Liege.

The furnace in use in Upper Silesia for the distillation of zinc is represented at Fig. 2398. The form of the retorts in which the distillation is carried on, is shown in section, Fig. 2399: the muffle R is about $3\frac{1}{2}$ ft. in length, and 1 ft. 8 in. in height: in the front are 2 openings $o\,o'$; in o' is inserted an earthen tube $t\,t'$ bent at right angles, and open at the lower extremity; in this tube the metal sublimes. The opening o is used for raking out the residual charge, and, when not being used, is closed by a clay stopple, well luted. At t is an opening in the tube by which the charge is introduced with a semi-cylindrical shovel. This opening is also closed during the distillation with a clay stopple. From 6 to 10 of these muffles are arranged in 2 rows on either side of the central fire-place. The arched openings in the furnace are closed

by means of iron plates when the muffles have been properly arranged; these plates prevent the too rapid cooling of the bent tube *t t'*, but a small door at *d*, Fig. 2398, can be opened when it is required to intro-

Fig. 2398. ZINC SMELTING-FURNACE. (*Silesian.*)

duce a charge into the muffle. The grate is shown at G, pit-coal being the fuel. The charge consists of equal bulks of roasted calamine (in pieces of about the size of a pea) and fine cinders from the grate, the latter being preferred to fine coal, the distilled pro-

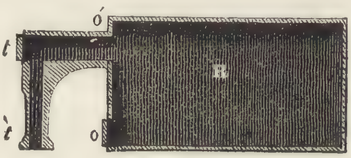


Fig. 2399.

ducts of which are apt to choke up the bent tube *t*. The preparatory process of roasting the calamine may be carried on in a separate furnace by means of the waste gases proceeding from the muffles. The reduced zinc escapes from the open end of the bent tube into vessels placed in openings *o o* of the furnace, Fig. 2398. Each operation is continued for 24 hours, and the residue is removed after every third distillation.

Zinc is largely used in the manufacture of brass, and also for making baths, water-tanks, spouts, pipes, plates for the engraver, for roofing, for voltaic-batteries, for covering iron, for sheathing for ships, and for many other purposes. Zinc tiles are remarkable for their lightness. The zinc of commerce is never pure, but is contaminated with lead, cadmium, iron, copper, &c.; but by dissolving it in sulphuric acid, filtering the solution, decomposing it with carbonate of potash, washing the precipitate, and heating it with powdered charcoal in an earthen or iron retort, the metal pure, or nearly so, may be distilled over into a vessel of water: the neck of the retort must be short and wide, to prevent the condensed metal from choking it up.

Zinc is of a bluish white colour, and its recent fracture presents a brilliant, crystalline surface. It is somewhat brittle at ordinary temperatures, but when heated to between 212° and 300° it becomes malleable and ductile, and may be rolled or hammered out without fracture; and, what is remarkable, it retains its malleability when cold: the sheet zinc of commerce is made in this way:—If the heat be increased to about 450°, the metal again becomes brittle, and may be reduced to powder in a mortar. Zinc fuses at about 773°, and by slow cooling exhibits a lamellar crystalline texture. At a bright red heat, zinc boils and volatilizes, and if air be admitted it burns with a vivid whitish blue light, generating the oxide, a white floculent matter, called by the older chemists *lana philosophica*, or philosopher's wool. Zinc is readily dissolved by dilute acids, and is used in preparing hydrogen gas. [See HYDROGEN.]

Oxide of zinc, ZnO, the only oxide of this metal, is a powerful base, isomorphous with magnesia: it is a white tasteless powder, not soluble in water, but freely so in acids: it becomes yellow by heat. When prepared by the combustion of the metal, it always contains small grains of the metal; but it may be purified by levigation. This substance has been proposed as a white paint instead of white lead, and has been largely manufactured for the purpose, in which case it is prepared by burning the metal, as it is first evolved from its ore in the reduction process. The objections to its use are stated in the INTRODUCTORY ESSAY, p. cxxxvi.

Sulphate of zinc, or *white vitriol*, $ZnO,SO_3,+7HO$, is prepared by dissolving the metal in dilute sulphuric acid, or more economically by roasting the native sulphuret, or blende, which by absorbing oxygen becomes to a great extent converted into the sulphate of oxide: the mineral is then thrown into hot water, and the salt is obtained by evaporating the clear solution. This salt closely resembles sulphate of magnesia in appearance; it has an astringent metallic taste, and is sometimes used as an emetic: the crystals are more soluble in cold than in hot water. This salt forms double salts with the sulphates of potash and ammonia.

Carbonate of zinc, ZnO,CO_2, is found native, as already noticed. The white precipitate, formed by mixing solutions of zinc and of alkaline carbonates, is a combination of carbonate and hydrate.

Chloride of zinc, ZnCl, may be readily prepared by dissolving zinc in hydrochloric acid. It is translucent and fusible, nearly white in colour, very soluble in water and in alcohol, and is very deliquescent. A strong solution is a convenient means of obtaining a graduated heat above 212°. Chloride of zinc combines with sal-ammoniac, and with chloride of potassium, to form double salts: the former, prepared by dissolving zinc in a proportionate quantity of hydrochloric acid, and then adding an equivalent of sal-ammoniac, is useful in tinning and soft-soldering copper and iron. [See SOLDERING.]

The zincing of iron, &c., is briefly noticed under ELECTROMETALLURGY, and also more fully under AMALGAM.

ZIRCONIUM (ZR 23), a rare metal, the oxide of which, *Zirconia*, ZrO, is found in the *Zircon*, or *Zargon*, and a few other minerals. The zircon is found in Ceylon, and when colourless and transparent, it is classed among the gems: when of a brown or red colour it is known as *hyacinth* or *jacinth*.

USEFUL TABLES.

TABLE I.—For converting French Decimal Measures and Weights into English Measures and Weights.

A. Measures of Length.

	1	2	3	4	5	6	7	8	9
Metre.—English Yards	1·09363	2·18727	3·28090	4·37453	5·46816	6·56180	7·65543	8·74906	9·84270
" Feet	3·28090	6·56180	9·84270	13·12360	16·40450	19·68539	22·96629	26·24719	29·52809
" Inches	39·37080	78·74158	118·11263	157·48315	196·85394	236·22473	275·59552	314·96630	354·33709
Decimetre.—Feet	0·32809	0·65618	0·98427	1·31236	1·64045	1·96854	2·29663	2·62472	2·95281
Inches	3·93708	7·87416	11·81124	15·74832	19·68539	23·62247	27·55955	31·49663	35·43371
Centimetre.—Inches	0·39371	0·78742	1·18112	1·57483	1·96854	2·36225	2·75596	3·14966	3·54337
Millimetre.—Inches	0·03937	0·07874	0·11811	0·15748	0·19685	0·23623	0·27560	0·31497	0·35434

B. Measures of Capacity.

	1	2	3	4	5	6	7	8	9
Cubic Centimetre.—Cubic Inch . . .	0·06103	0·12205	0·18308	0·24411	0·30514	0·36616	0·42719	0·48822	0·54924
Litre.—English Imperial Gallons . . .	0·22017	0·44033	0·66050	0·88066	1·10083	1·32100	1·54116	1·76133	1·98149
" " Quarts . . .	0·88066	1·76133	2·64199	3·52266	4·40332	5·28398	6·16465	7·04531	7·92598
" " Pints	1·76133	2·52266	5·28399	7·04531	8·80664	10·56797	12·32930	14·09062	15·85195
Stere.—Gallons	220·16643	440·33287	660·49930	880·66574	1100·83217	1320·99860	1541·16504	1761·33147	1981·49791

C. Weights.

	1	2	3	4	5	6	7	8	9
Killogramme.—Cwt.	0·01970	0·03939	0·05909	0·07879	0·09848	0·11818	0·13788	0·15758	0·17727
lb. (avoird.)	2·20486	4·40971	6·61457	8·81943	11·02428	13·22914	15·43400	17·63886	19·84371
Killogramme.—lb. (troy)	2·67951	5·35903	8·03854	10·71805	13·39757	16·07708	18·75659	21·43610	24·11562
Gramme.—Grains	15·44242	30·88484	46·32726	61·76968	77·21210	92·65352	108·09694	123·53936	138·98178
Decigramme.—Grains	1·54424	3·08848	4·63273	6·17697	7·72121	9·26535	10·80969	12·35394	13·89818
Centigramme.—Grains	0·15442	0·30885	0·46327	0·61770	0·77212	0·92654	1·08097	1·23539	1·38982
Milligramme.—Grains	0·01544	0·03089	0·04633	0·06177	0·07721	0·09265	0·10810	0·12354	0·13898

These tables are given in Gmelin's *Chemistry*, vol. ii. (Cavendish Society's Translation.) They are arranged on the same plan as the Analytical Tables in Rose's *Analytical Chemistry*, and other works of similar character. One example may suffice to illustrate the mode of using them. Let it be required to find how many grains are equal to 87·435 grammes:—

By Column 8	line 4	of Table C,	we find:	80	grammes	=	1235·3936	grains.
" 7	" 4	"	"	7	"	=	108·0969	"
" 4	" 5	"	"	·4	"	=	6·1770	"
" 3	" 6	"	"	·03	"	=	0·4633	"
" 5	" 7	"	"	·005	"	=	0·0772	"
				87·435	grammes	=	1350·2080	grains.

TABLE II.—Barometer Scale in Millimetres and Inches.

Mm.	In.	Mm.	In.	Mm.	In.
700	= 27·560	730	= 28·741	760	= 29·922
701	= 27·590	731	= 28·780	761	= 29·961
702	= 27·638	732	= 28·819	762	= 30·000
703	= 27·678	733	= 28·859	763	= 30·040
704	= 27·717	734	= 28·898	764	= 30·079
705	= 27·756	735	= 28·938	765	= 30·119
706	= 27·795	736	= 28·977	766	= 30·158
707	= 27·835	737	= 29·016	767	= 30·197
708	= 27·876	738	= 29·056	768	= 30·237
709	= 27·914	739	= 29·095	769	= 30·276
710	= 27·953	740	= 29·134	770	= 30·315
711	= 27·992	741	= 29·174	771	= 30·355
712	= 28·032	742	= 29·213	772	= 30·384
713	= 28·071	743	= 29·252	773	= 30·434
714	= 28·111	744	= 29·292	774	= 30·473
715	= 28·150	745	= 29·331	775	= 30·512
716	= 28·189	746	= 29·371	776	= 30·552
717	= 28·229	747	= 29·410	777	= 30·591
718	= 28·268	748	= 29·449	778	= 30·631
719	= 28·308	749	= 29·489	779	= 30·670
720	= 28·347	750	= 29·528	780	= 30·709
721	= 28·386	751	= 29·567	781	= 30·749
722	= 28·426	752	= 29·607	782	= 30·788
723	= 28·465	753	= 29·646	783	= 30·827
724	= 28·504	754	= 29·685	784	= 30·867
725	= 28·543	755	= 29·725	785	= 30·906
726	= 28·583	756	= 29·764	786	= 30·945
727	= 28·622	757	= 29·804	787	= 30·985
728	= 28·661	758	= 29·843	788	= 31·024
729	= 28·701	759	= 29·882	789	= 31·063

28 inches = 711·187 millimetres.
29 „ = 735·587 „
30 „ = 761·986 „
31 „ = 787·386 „

1 millimetre = 0·03937 inch.
0·1 „ = 0·00394 „
0·01 „ = 0·00039 „

1 inch = 25·39954 millimetres.
0·1 „ = 2·53995 „
0·01 „ = 0·25400 „
0·001 „ = 0·02540 „

TABLE III.—For converting Degrees of the Centigrade Thermometer into Degrees of Fahrenheit's Scale.

Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.
− 100° ...	− 148·0°	− 85° ...	121·0°	− 70° ...	− 94·0°	− 55° ...	− 67·0°
99 ...	146·2	84 ...	119·2	69 ...	92·2	54 ...	65·2
98 ...	144·4	83 ...	117·4	68 ...	90·4	53 ...	63·4
97 ...	142·6	82 ...	115·6	67 ...	88·6	52 ...	61·6
96 ...	140·8	81 ...	113·8	66 ...	86·8	51 ...	59·8
95 ...	139·0	80 ...	112·0	65 ...	85·0	50 ...	58·0
94 ...	137·2	79 ...	110·2	64 ...	83·2	49 ...	56·2
93 ...	135·4	78 ...	108·4	63 ...	81·4	48 ...	54·4
92 ...	133·6	77 ...	106·6	62 ...	79·6	47 ...	52·6
91 ...	131·8	76 ...	104·8	61 ...	77·8	46 ...	50·8
90 ...	130·0	75 ...	103·0	60 ...	76·0	45 ...	49·0
89 ...	128·2	74 ...	101·2	59 ...	74·2	44 ...	47·2
88 ...	126·4	73 ...	99·4	58 ...	72·4	43 ...	45·4
87 ...	124·6	72 ...	97·6	57 ...	70·6	42 ...	43·6
86 ...	122·8	71 ...	95·8	56 ...	68·8	41 ...	41·8

TABLE III. *(continued.)*

Cent.	Fah.	Cent.	Fah.	Cent.	Fah.	Cent.	Fah.
− 40°	− 40·0°	+ 27°	+ 80·6°	+ 94	+ 201·2°	+ 161°	+ 321·8°
39	38·2	28	82·4	95	203·0	162	323·6
38	36·4	29	84·2	96	204·8	163	325·4
37	34·6	30	86·0	97	206·6	164	327·2
36	32·8	31	87·8	98	208·4	165	329·0
35	31·0	32	89·6	99	210·2	166	330·8
34	29·2	33	91·4	100	212·0	167	332·6
33	27·4	34	93·2	101	213·8	168	334·4
32	25·6	35	95·0	102	215·6	169	336·2
31	23·8	36	96·8	103	217·4	170	338·0
30	22·0	37	98·6	104	219·2	171	339·8
29	20·2	38	100·4	105	221·0	172	341·6
28	18·4	39	102·2	106	222·8	173	343·4
27	16·6	40	104·0	107	224·6	174	345·2
26	14·8	41	105·8	108	226·4	175	347·0
25	13·0	42	107·6	109	228·2	176	348·8
24	11·2	43	109·4	110	230·0	177	350·6
23	9·4	44	111·2	111	231·8	178	352·4
22	7·6	45	113·0	112	233·6	179	354·2
21	5·8	46	114·8	113	235·4	180	356·0
20	4·0	47	116·6	114	237·2	181	357·8
19	2·2	48	118·4	115	239·0	182	359·6
18	0·4	49	120·2	116	240·8	183	361·4
17	+ 1·4	50	122·0	117	242·6	184	363·2
16	3·2	51	123·8	118	244·4	185	365·0
15	5·0	52	125·6	119	246·2	186	366·8
14	6·8	53	127·4	120	248·0	187	368·6
13	8·6	54	129·2	121	249·8	188	370·4
12	10·4	55	131·0	122	251·6	189	372·2
11	12·2	56	132·8	123	253·4	190	374·0
10	14·0	57	134·6	124	255·2	191	375·8
9	15·8	58	136·4	125	257·0	192	377·6
8	17·6	59	138·2	126	258·8	193	379·4
7	19·4	60	140·0	127	260·6	194	381·2
6	21·2	61	141·8	128	262·4	195	383·0
5	23·0	62	143·6	129	264·2	196	384·8
4	24·8	63	145·4	130	266·0	197	386·6
3	26·6	64	147·2	131	267·8	198	388·4
2	28·4	65	149·0	132	269·6	199	390·2
1	30·2	66	150·8	133	271·4	200	392·0
0	32·0	67	152·6	134	273·2	201	393·8
+ 1	33·8	68	154·4	135	275·0	202	395·6
2	35·6	69	156·2	136	276·8	203	397·4
3	37·4	70	158·0	137	278·6	204	399·2
4	39·2	71	159·8	138	280·4	205	401·0
5	41·0	72	161·6	139	282·2	206	402·8
6	42·8	73	163·4	140	284·0	207	404·6
7	44·6	74	165·2	141	285·8	208	406·4
8	46·4	75	167·0	142	287·6	209	408·2
9	48·2	76	168·8	143	289·4	210	410·0
10	50·0	77	170·6	144	291·2	211	411·8
11	51·8	78	172·4	145	293·0	212	413·6
12	53·6	79	174·2	146	294·8	213	415·4
13	55·4	80	176·0	147	296·6	214	417·2
14	57·2	81	177·8	148	298·4	215	419·0
15	59.0	82	179·6	149	300·2	216	420·8
16	60·8	83	181·4	150	302·0	217	422·6
17	62·6	84	183·2	151	303·8	218	424·4
18	64·4	85	185·0	152	305·6	219	426·2
19	66·2	86	186·8	153	307·4	220	428·0
20	68·0	87	188·6	154	309·2	221	429·8
21	69·8	88	190·4	155	311·0	222	431·6
22	71·6	89	192·2	156	312·8	223	433·4
23	73·4	90	194·0	157	314·6	224	435·2
24	75·2	91	195·8	158	316·4	225	437·0
25	77·0	92	197·6	159	318·2	226	438·8
26	78·8	93	199·4	160	320·0	227	440·6

TABLE III. (*continued.*)

Cent.		Fah.	Cent.		Fah.	Cent.		Fah.	Cent.		Fah.
+ 228°	...	+ 442·4°	+ 258°	...	+ 496·4°	+ 289°	...	+ 552·2°	+ 320°	..	+ 608·0°
229	...	444·2	259	...	498·2	290	...	554·0	321	...	609·8
230	...	446·0	260	...	500·0	291	...	555·8	322	...	611·6
231	...	447·8	261	...	501·8	292	...	557·6	323	...	613·4
232	...	449·6	262	...	503·6	293	...	559·4	324	...	615·2
233	...	451·4	263	...	505·4	294	...	561·2	325	...	617·6
234	...	453·2	264	...	507·2	295	...	563·0	326	...	618·8
235	...	455·0	265	...	509·0	296	...	564·8	327	...	620·6
236	..	456 8	266	...	510·8	297	...	566·6	328	...	622·4
237	...	458·6	267	...	512·6	298	...	568·4	329	...	624·2
238	...	460·4	268	...	514·4	299	...	570·2	330	...	626·0
239	...	462·2	269	...	516·2	300	...	572·0	331	...	627·8
240	...	464·0	270	...	518·0	301	...	573·8	332	..	629·6
241	...	465·8	271	...	519·8	302	...	575·6	333	...	631·4
242	...	467·6	272	...	521·6	303	..	577·4	334	...	633·2
243	...	469·4	273	...	523·4	304	...	579·2	335	...	635·0
244	...	471·2	274	...	525·2	305	...	581·0	336	...	636·8
245	...	473·0	275	...	527·0	306	...	582·8	337	..	638·6
246	...	474·8	276	...	528·8	307	...	584·6	338	...	640·4
247	...	476·6	277	...	530·6	308	...	586·4	339	...	642·2
248	...	478·4	278	...	532·4	309	...	588·2	340	...	644·0
249	...	480·2	279	...	534·2	310	...	590·0	341	...	645·8
250	...	482·0	280	...	536·0	311	...	591·8	342	...	647·6
251	...	483·8	281	...	537·8	312	...	593·6	343	...	649·4
252	...	485·6	282	...	539·6	313	...	595·4	344	...	651·2
253	...	487·4	283	...	541·4	314	...	597·2	345	...	653·0
254	...	489·2	284	...	543·2	315	...	599·0	346	...	654·8
255	...	491·0	285	...	545·0	316	...	600·8	347	...	656·6
256	...	492·8	286	...	546·8	317	...	602·6	348	...	658·4
257	...	494·6	287	...	548·6	318	...	604·4	349	...	660·2
			288	...	550·4	319	...	606·2			

TABLE IV.—The Proportion by Weight of Absolute or Real Alcohol in 100 parts of Spirits of different Specific Gravities. (*Fownes.*)

Sp. Gr. at 60° (15·5° C).	Per centage of Real Alcohol.	Sp. Gr. at 60° (15·5° C).	Per centage of Real Alcohol.	Sp. Gr. at 60° (15·5° C)	Per centage of Real Alcohol.	Sp. Gr. at 60° (15·5° C).	Per centage of Real Alcohol.
0·9991	0·5	0·9652	25	0·9184	50	0·8603	75
0·9981	1	0·9638	26	0·9160	51	0·8581	76
0·9965	2	0·9623	27	0·9135	52	0·8557	77
0·9947	3	0·9609	28	0·9113	53	0·8533	78
0·9930	4	0·9593	29	0·9090	54	0·8508	79
0·9914	5	0·9578	30	0·9069	55	0·8483	80
0·9898	6	0·9560	31	0·9047	56	0·8459	81
0·9884	7	0·9544	32	0·9025	57	0·8434	82
0·9869	8	0·9528	33	0·9001	58	0·8408	83
0·9855	9	0·9511	34	0·8979	59	0·8382	84
0·9841	10	0·9490	35	0·8956	60	0·8357	85
0·9828	11	0·9470	36	0·8932	61	0·8331	86
0·9815	12	0·9452	37	0·8908	62	0·8305	87
0·9802	13	0·9434	38	0·8886	63	0·8279	88
0·9789	14	0·9416	39	0·8863	64	0·8254	89
0·9778	15	0·9396	40	0·8840	65	0·8228	90
0·9766	16	0·9376	41	0·8816	66	0·8199	91
0·9753	17	0·9356	42	0·8793	67	0·8172	92
0·9741	18	0·9335	43	0·8769	68	0·8145	93
0·9728	19	0·9314	44	0·8745	69	0·8118	94
0·9716	20	0·9292	45	0·8721	70	0·8089	95
0·9704	21	0·9270	46	0·8696	71	0·8061	96
0·9691	22	0·9249	47	0·8672	72	0·8031	97
0·9678	23	0·9228	48	0·8649	73	0·8001	98
0·9665	24	0·9206	49	0·8625	74	0·7969	99
						0 7938	100